The Geography and Geology of Minnesota

VOLUME ONE

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The Winnebago Valley.
Photograph by C. J. Hibbard.

GEOGRAPHY AND GEOLOGY OF MINNESOTA

VOLUME I

GEOGRAPHY OF MINNESOTA

BY

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MINNEAPOLIS

THE H. W. WILSON COMPANY

1903

Illustrated by
Bureau of Engraving

PREFACE

The theme of this book is the Geography of Minnesota in its most essential and fundamental aspects. While the principles set forth are world-wide in their application, the illustrations used to enforce them are drawn almost wholly from the features and phenomena of the state. Wherever state lines are ignored and the boundary is crossed it is to secure what seems necessary to make clear the causes of conditions about us. For instance: almost the whole state presents manifold evidence of the work of glaciers; to show a glacier and its setting as a physical factor, appeal is made to the Yoho valley near the summit of the Albertan Rockies. Figure 29, Chapter VIII, is a picture of the interesting Yoho glacier. As the pupil looks at this picture and, in imagination, sees it expand into an ice stream hundreds of miles long and scarcely less in width, its moraines, in places, looming up hundreds of feet high and its wash filling prairies and plains scores of feet in depth, with identically the same materials as one finds everywhere throughout the state, there will become clear to the mind conditions well-nigh universal in Minnesota only a few thousand years ago.

This book is not written in the style usual in text books of the schools. It is prepared rather to read,

and for reference to such conspicuous geographic features as are presented in the physical make-up of the state. Its aim is to instruct: to that end simple, concise definition is a leading feature. Wherever practicable each topic opens with such defining of terms as seems necessary to make description and discussion clear. This treatment has been followed, that in the hands of those desiring to learn about the state, the larger, world-wide principles will be recognized from which broad generalizations always come.

A feature of the book is the illustration of every chapter. Each figure is placed as near the subject it illustrates as the make-up of the pages would permit. The descriptions of the figures often carry explanations supplementary to the text. To former students many sketches and half-tones will prove familiar, for most of the maps, profiles and photographs used are classroom equipment in the University.

Again, it is not the purpose of the book to tell it all nor to call attention to everything of a geographic nature within the state. If interest be aroused and attention directed in a plain, scientific way to the wealth of geographic illustration Minnesota affords, the object of the author is realized.

Acknowledgements are due to many. Had not teachers of the state called for such a work and urged its preparation, these pages would never have been written. Especial courtesies have been extended by Professor MacMillan, state botanist, and by Mr. T. S. Outram, section Director of the U. S. Weather Bureau; Miss Mary Pollard proof-read the manuscript, Miss Nellie Muller prepared the index and Miss Ellen Janney made the most and the best of the pen illustrations.

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The figures in this list over the name of C. J. Hibbard are from negatives in the collection of the Botanical Survey of the State; those over H. F. Nachtrieb's name from negatives of the Zoological Survey. These illustrations are due to the courtesy of the State Botanist and State Zoologist.

GEOGRAPHY OF MINNESOTA

CHAPTER I.

MINNESOTA.

Situation—Surface—Boundaries—Extent and Area.

GEOGRAPHICALLY, Minnesota has a central position in North America. Not only is it exactly midway between Wisconsin and the Dakotas, but it lies equidistant between Beaufort sea and the Gulf of Mexico, and half way from the Gulf of California to the Gulf of Saint Lawrence. It is just about as far from the capital of the state to the summits of the Cuban mountains as to Mount McKinley, the highest peak of North America. Lake Mille Lacs is half way from Cape Saint Lucas to Cape Farewell. A buoy placed in Bering strait is as far from the great port of Duluth as one off the south end of the prospective isthmian canal in the Bay of Panama.

Physiographically, Minnesota occupies a crest of the continent. While its height above the sea is not great,—being 2230 feet maximum and 602 feet minimum of altitude,—it includes the sources of three of the great river systems of the continent. Flowing northward is the Red River of the North reaching the ocean through Hudson bay; flowing eastward is the Saint Lawrence whose upper course is called the Saint Louis, reaching the Atlantic through the Gulf of Saint Law-

rence, and southward pours the Mississippi. A branch of the Missouri also rises in the state.

The state is very old. Its volcanoes—and it has been shaken by many eruptions—are so old that not even their necks or conical mounds can now be found

Fig. 1. The position of Minnesota in North America. The principal drainage basins of the continent are outlined.

Its mountains, too, have been worn down until their flattened stumps remain. That the Minnesota mountains were once high and grand is shown by the great beds of sandstone now lying spread out beneath the southeastern portion of the state and the thousands of square miles in neighboring states.

Botanically, the state lies partly within the prairie and partly within the forest region of the continent. Of the prairie, modest grasses are the dominant plant population; of the forest, stately trees. These forms

Fig. 2. A typical forest scene, the school house at Lutsen in the foreground. "Coniferous forests stretch * * * their somber shades."
Photograph by Hibbard, Botanical Survey, Minnesota.

of vegetation have long been here, and from the very first have waged ceaseless warfare against each other for the ground in which they live and from which they

draw their nourishment. They came from different directions—the forest trees chiefly from the north, and the prairie grasses in largest numbers from the south, the former controlling by spreading overshadowing branches and enveloping with depressing shade, and the latter by pushing their way underground, seeking spots where sunshine falls and extracting on their way the soil-nourishment they need. Thus the humbler grasses may deprive the more stately trees of necessary food.

Zoologically, the state is favorably situated for impressing the influence of environment upon a fauna.

Fig, 3. **A view among the Leaf hills, with Eagle lake in the foreground, "a beautiful diversity of lake and rolling prairie."**
Photograph by Warren Upham, for U. S. Geological Survey.

The basins of great rivers direct the migrations of numerous creatures. Fish, for instance, pass from one drainage basin to another at many points over low or shifting divides. River piracy is an incident in these migrations; so too, are the lakes of the state whence waters flow in opposite directions. The border line of forest and prairie is efficient in promoting animal migrations. The prairies grazed the buffalo and antelope; the forests afforded homes and lurking places for many flesh eaters.

Boundaries. The boundaries of Minnesota are partly natural: Instance Lake of the Woods with Rainy River waterway, Pigeon river, and lake Superior on the north and northeast; the Saint Louis, Saint Croix, and Mississippi rivers along the east side; lakes Big Stone and Traverse, and Red River of the north along the west side. Other portions of the boundary are arbitrarily drawn upon certain meridians and par-

Fig. 4. A scene on Winnebago creek, southeastern Minnesota where are seen "charming vistas of retreating valleys."
Photograph by Hibbard for Botanical Survey, Minnesota.

allels. The Iowa line is along parallel 43° 30′; the northern line on the 49th from the Red River to Lake of the Woods. Inasmuch as the northern boundary of the state is that of the national domain, its northernmost point is the northernmost of the United States save Alaska, to-wit, the projection into the "most northwestern point of Lake of the Woods," which extends it to 49° 23′ 50.28″ N. This is 22.85 miles north

of the 49th parallel. West and east two meridians are paralleled; next South Dakota, longitude 97° 5′ from Big Stone lake to Iowa, and next Wisconsin, 87° 39′ between the rivers Saint Louis and Saint Croix.

Extent and Area. The greatest distance across the state is from north to south, about 400 miles; the greatest width, from Saint Vincent to Pigeon Point, is 357 miles. Yet a crow may fly less than 180 miles in going from Wisconsin to South Dakota, between the mouth of Goose creek and the foot of Big Stone lake.

Thus delimited, Minnesota contains, if its lake surfaces and marginal waters are included, 84,286.53 square miles, or 53,943,379 acres. Of this domain 5,637.53 square miles are of water surface. There is left 78,649 square miles, or 50,335,367 acres of land, enough to make 314,596 farms of 160 acres each, the largest amount that can be taken by one citizen under the national homestead laws. In comparison with other states, only nine contain more square miles, eighteen showed a greater population in 1900, and eighteen have been longer in the Union.

CHAPTER II.

RELIEF.

Contours—Contours followed—Practical notes.

THE UNEVENNESS of land surface is called Relief. It has already been noted that Minnesota is not high; yet it has in places considerable relief. In its northeastern corner, the state lies lowest and highest. Lake Superior is 602.2 feet above the tide; the Misquah hills reach 2,230 feet. This, taken relatively, is not high land; there is no point in Wisconsin, Michigan, Illinois, or Iowa as high as are several peaks of the Misquah hills and the Giants range; yet one-half of South Dakota, and two-fifths of North Dakota attain a greater altitude than the highest peak in Minnesota.

The waters of the state naturally are not so high as the land. Lake Abita in the Misquah hills is 2,048 feet; several other lakes in northeastern Minnesota are above 1,900 feet. Elsewhere lakes show considerable altitude, but nowhere do they attain the height of the rock-bound bodies of water in the northeastern corner.

Contours are lines drawn through points at equal distances above the level of the sea. They may be imagined to mark the shore line of the ocean at successive stages of its rise and fall. They are placed a cer-

tain number of feet apart, as 100, or 50, or 20, and, where greater accuracy is desired, at a still smaller distance, as 5 or 2 feet. Most maps of Minnesota show contour lines 20 and 50 feet apart.

The map herewith shows contours 250 feet apart. The lowest one marks the position where a plane 750 feet above the sea cuts the surface of the state. Following this contour, we see that a narrow belt along the Mississippi river is terminated at the Falls of Saint Anthony. Along the Saint Croix river from its confluence with the Mississippi at Point Douglas nearly to the mouth of Sunrise creek in northern Chisago county, a strip can be followed; and from Fort Snelling the bottom lands of the Minnesota are beneath this invisible plane to a point beyond Saint Peter. Finally, along the Lake Superior coast from Pigeon bay to the Dalles of the Saint Louis, for the most part closely skirting the lake shore, this contour stretches.

Follow next the line indicating where the 1,000-foot contour cuts the surface of the state. Nearly or quite three-fifths lies below it. In northeastern Minnesota beginning with the Pigeon river just above the beautiful Pigeon falls, the point where this plane enters the state from Ontario. It passes down Pigeon bay, cuts across the point to the Lake Superior slope, and follows this slope at a comparatively short distance from the shore of the lake, through the city of Duluth, and up the Saint Louis river into the Dalles. The strip between the lake shore and the 1,000-foot contour is quite narrow. On Pigeon point, where this contour is first seen, the point is less than one mile across. At Two Harbors, the Duluth and Iron Range railway, seeking the most favorable grade to the mines, crosses the contour within three miles of the ore-docks, which means a grade of about 125 feet to the mile. Within the city of Duluth, the contour is within four-fifths of a mile of the harbor.

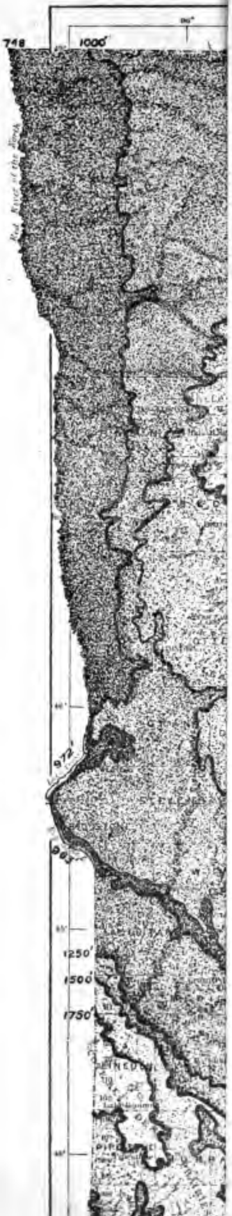
Beginning in southeastern Minnesota, where the Mississippi leaves the state at 626 feet above the sea, this 1,000-ft. plane intersects the Iowa-Minnesota boundary only four miles from the main Mississippi channel. From this point to the vicinity of Saint Paul the plane intersects the land in a most tortuous and ragged way, and at a comparatively short distance from the river.

On the eastern border of the state, where the Saint Croix flows altogether within Wisconsin, this contour lies back from the river one and one-half miles.

Returning to Point Douglas, we follow the Mississippi river northwest up a narrow valley to Peace Rock, a huge granite mass picturesque in the early history of Minnesota.

At Fort Snelling, meandering along the course carved for it by that remarkable stream of olden time, the River Warren, flows the Minnesota. The 1,000-foot plane cuts its valley in Burnsville on the east side and Eden Prairie on the west, seven miles apart as the crow flies. The contacts of earth and plane are not far apart, yet on the whole constantly narrowing as we ascend the Minnesota, until at Ortonville the span can be measured in hundreds of feet, and at Browns Valley, where one steps from the Minnesota river valley into the area of the Red River of the North, the span can be crossed by the High School sprinter in a very few seconds.

At Browns Valley the Red River valley begins, that world-renowned lake bottom of ancient Agassiz, now known as the greatest wheat producing region



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in the world. The area below 1,000 feet stretches eastward until it is many miles in width in Kittson ~~and Roseau~~ counties. Thus the divide between the drainage basin of Hudson Bay and the Gulf of Mexico lies in this state, and is beneath the 1,000-foot plane. Its height at Browns Valley is 973 feet.

A comparatively small area of the state lies above the contour of 1,500 feet. This consists of three separate tracts. In northeastern Minnesota, Cook and Lake counties are largely above it; a belt runs from Saint Louis county into Itasca along the Giants range, while many smaller areas and knobs of solid rock and glacial drift to the north are more than 1,500 feet high. In southwestern Minnesota, the great Coteau stretches from 1,500 feet to 2,000 feet above the sea. This high land was known to the early explorers as the Shining mountains. For them it was a treeless land; its long slopes stood out in the haze of summer—the only season when seen by the white man—seemingly high and inhospitable. The buffalo grazed along its slopes for centuries; beyond its summits lay the quarries whence was dug the red stone on which were carved rude artistic lines, and out of which were wrought fantastic pipes.

Passing northward many miles from this coteau, a few small areas in the Leaf Hills region and around the Mississippi and Red River of the North lie between two planes of 1,500 feet and 2,000 feet. This surface is small compared with the northeastern and southwestern areas.

Practical Notes. We see, therefore, that the term "Height of Land" which has been used so many times in geographic descriptions of Minnesota is a misnomer. The highest land is in the northeastern corner and within a few miles of the International boundary. The "Height of Land" heretofore referred to lies largely within that average zone between the planes of 1,000 and 1,500 feet above the sea.

The average altitude of the state is almost exactly 1,200 feet. This is not so high as has usually been estimated. A careful computation by townships gives 41,897 square miles above the 1,200 foot contour and 42,390 square miles below the 1,200 foot contour plane. The computation was made from the topography of the Minnesota geological survey, the quadrangles of the United States geological survey so far as completed, and the various railway surveys.

Another practical consideration upon Relief is that the state is not peculiarly subject to floods. The long, low slopes will not gather water quickly into great

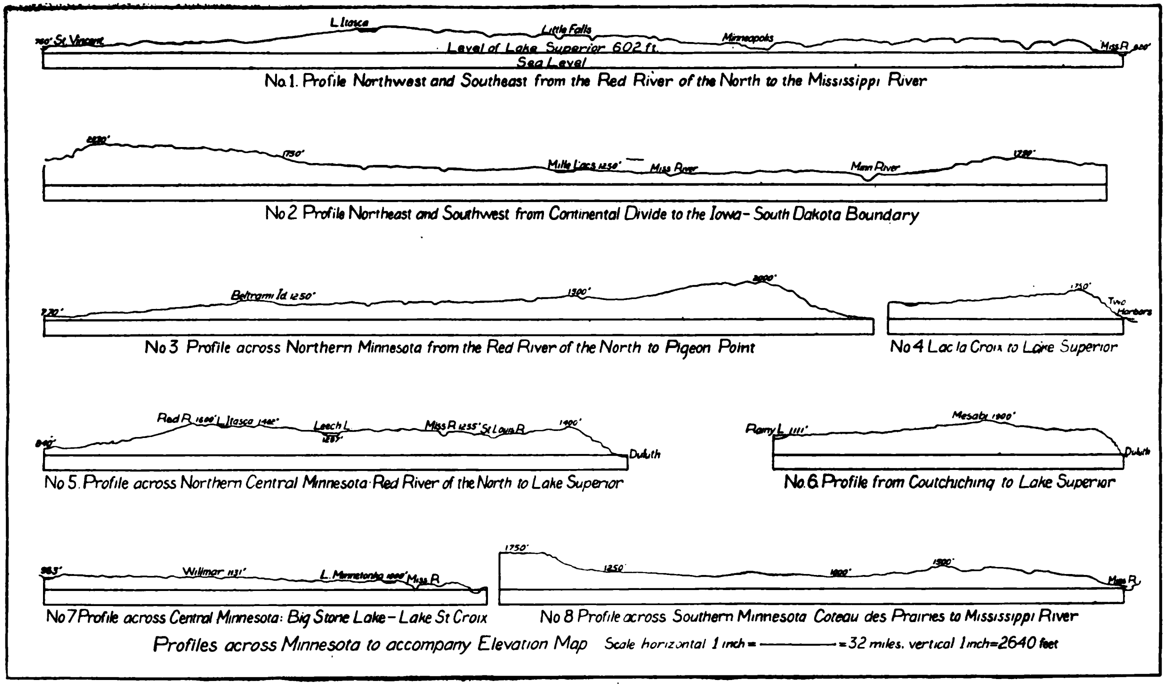

Plate II. "Minnesota has not always been the great, level, drift-covered region it is to-day."

volumes or roll it off readily. Neither is the state a region of marshes and malaria, a favorable condition determined by high latitude rather than gentle altitude.

Minnesota has not always been the great, level, drift-covered region it is today. This condition is the resultant of slow and ceaseless processes involving movements of vast extent. It has many times been beneath the sea; it has been a part of the endless shore lines, and coastal plains have occupied its area in successive belts from south to north in broad stretches of low, level land. Finally, and still longer ago, it was the floor from which have arisen hills and mountains of great height and magnitude.

CHAPTER III.

MINNESOTA AIR.

Definitions—Air as an ocean—Chemical composition—Elements—Wind—Direction of wind—Destructiveness of winds—Air as a physiographic agent—Practical notes.

TWO DEFINITIONS must here be stated:

Air is the mixture of gases that forms the blue envelope of the earth.

Atmosphere is the body of the great outer earth-envelope.

Air consists of gases. Oxygen, nitrogen, water, vapor and carbon dioxide are the chief. Atmosphere comprises these, all the space between their molecules, and the unmeasured and immeasurable ether, whatever that may be. The air can be determined chemically; the atmosphere has thus far disclosed only certain qualities.

Air-pressure is due to the elasticity of imprisoned and confined gases, as on the piston of an engine; atmospheric pressure is the weight of the earth envelope, gases, ether, and all else in the space above us, bearing down upon the waters and the land.

Noxious air and malarial atmosphere are spoken of; a person may carry himself with a lordly air; the social

atmosphere is delightful and stimulating. In short, one term is narrow and specific; the other broad and generic.

Geographers like to tell us that we walk about on the bottom of an ocean of air which is possibly 800 to 1000 miles in depth. Sometimes we raise ourselves and float about a short distance above the bottom of this air-ocean, and again burrow beneath it; but never where it cannot pour its flood of life-giving fluid. The air-ocean, like the water-ocean, grows lighter toward its top, until its lightness is no longer known. 13⅓ cubic feet of air weighs a pound; thus the air of an average sized school room, 30x30x12 feet, will weigh over 813 pounds at the seashore; its weight at the average altitude of Minnesota school-houses, which is 1,200 feet above the sea, is about 786 pounds.

The weight of the atmosphere is measured with the barometer, an instrument in which the air balances a column of mercury. This balancing is so delicately adjusted that any change in the bearing down of the air upon the earth, its pressure, is indicated by the mercury. The weight of the air when the mercury column is 30 inches high is 15 pounds on every square inch of surface—the weight of the mercury being one-half pound per cubic inch. Hence when the mercury falls from 30 to 29 inches as a "low wave" approaches, the weight of the atmosphere on every square inch of ground decreases by half a pound. Mr. Outram says that the highest point recorded by the barometer in

Fig. 5.
High Barometer. Reading for Minnesota, Jan. 15, 1902.

Minnesota since 1871, is 31.01 inches on February 3, 1893, and the lowest 28.80 inches on February 28, 1902. This difference is not so great as has been noted in some other parts of the world. Minnesota has few terrific storms and few earthquakes. What relation there is between the two circumstances cannot here be discussed.

Chemical Composition. Chemically considered, the atmosphere is a most interesting mixture. It has been weighed and measured by hundreds of investigators. They find it is in no two places absolutely the same. For Minnesota this table gives nearly the correct figures:

Nitrogen	769.0600
Oxygen	206.5940
Water	14.0000
The newly found constituents Argon, Helium, Xenon, Krypton, and others	10.0000
Carbon dioxide	0.3360
Ammonia	0.0080
Ozone	0.0015
Nitric oxide	0.0005
Total contents	1000.0000

Fig. 6. Low Barometer. Reading in Saskatchewan same date as preceding "high" in Minnesota.

Let us now consider very briefly a part of the constituents.

Nitrogen is the most abundant gas the air contains. It has no injurious effects upon living things, animal or vegetable. It has no effects toward maintaining life. Its office is that of a dilutant, to make effective other constituents and form a body to the atmosphere. It is in this last office that its effects are noted; when the wind blows it is chiefly nitrogen that strikes our bodies and sways the trees; nitrogen affords the cushion that eases down beautiful snowflakes and retards rushing meteorites. A lightning flash causes salts of ammonia to form by bringing about the chemical union of nitrogen, hydrogen and

oxygen with other substances, and thereby giving food to plants. This is one way thunder storms refresh vegetation.

Oxygen is the life-sustaining element of the air. Its proportion is strikingly similar in every open place upon sea and land; at the highest place from which baloonists have taken air for analysis. It is not only a necessity for all animal life and plants, but is also a wonderful storehouse of energy, searching out other elements and uniting with them into those chemical compounds which are met with everywhere.

Ozone. Chemists are not certain that ozone exists ordinarily in the air. Electricity generates it and its presence is detected by a peculiar pungent odor and the reactions which it produces. After a shower, with much thunder and lightning, has washed the air of some millions of its microbes and dust particles, we take in a long breath and feel we are inhaling great quantities of ozone. We are, as quantities of ozone are understood. Filling our lungs repeatedly for fifteen minutes, we take in about 21 cubic feet of the clean air. It would take five days to breath the entire contents of our school room. The school room contains ozone enough to take the indigo coloring out of several drops of washerwoman's bluing.

Carbonic Acid. If we could measure the carbonic acid the well-aired school room contains, we should find a very small quantity. Were it combined with such lime as is made in any limekiln in the state, it would yield a crystal of calcite or dolomite 2 inches on a side. Wait until recess; measure the carbonic acid again when the ventilation has not been attended to, and a crystal 4 inches on a side and weighing over four pounds could be built.

Vapor in the Air. Minnesota air is usually dry. Still the term dry is a relative one. We never mean it is destitute of moisture; but simply that, compared with the atmosphere of New Orleans, London or Seattle, it contains very little water. The exact amount varies from hour to hour. The moisture in the air plays an important function. All rainstorms depend upon it; seasons of drought are due to its absence, and the clearness and transparency of the air are largely due to the degree of saturation of the space devoted to atmospheric elements. The 'humidity' of the atmosphere is a subject of daily observation and determination by every observer.

Dust is another important content of the air. This term includes many things such as microbes, whatever these may be, smoke and rock particles loosened and carried forward by the wind. The presence of all these dulls the blueness of the atmosphere, gives a haziness to it as we look abroad, makes fog, since tiny particles of water adhere to the foreign substances, and even promotes the formation of rain. Every form of dust is injurious to health.

Wind. The ocean of atmosphere is as restless as the ocean of water. Air is perpetually in motion. This is wind. Its movement is measured in miles per hour. For more than half the year the rate of Minnesota wind is less than 10 miles. A strong prairie breeze moves 25 miles, the average progress of a railway passenger train over the prairies. The highest wind re-

corded for 1900 was 54 miles per hour at Duluth on February 8th. This was called a violent gale. In this gale the wind struck with a force of 15 pounds per square foot. An average sized man in his overcoat and unprotected had to stand up against a force of 100 pounds. It was like receiving a half-barrel sack of flour driven against him.

Winds from the northwest prevail in the state. By that we mean that a northwest wind blows about 200 days of the 365. A southwest wind is the next most frequent, while an east wind blows only 15 or 20 days in the year. Variability in direction is one marked feature of wind. It yields space and moves away from any given area on the application of the slightest pressure. It blows, that is, it moves forward, in gusts even in the slightest breezes. When the strongest winds blow we have the intensest gusts, now upwards, now downwards, now right, now left. The great area, the cyclone, moves steadily forward.

Direction of Wind. While the state lies within the belt of the "prevailing westerlies," Minnesota winds are occasional. The atmosphere is never equally heated over a large area; a lake surface never gets so hot as the neighboring land in summer nor so cold in winter until ice shuts in its warmth. Extending this area to prairies and forests, hills and valleys, fields and pastures, we see the reason for prevailingly occasional winds.

Destructiveness of Winds. Hot winds blast plant life with merciless fury. They are remarkably free from water vapor; their temperature is high; their velocity is great. So the three essential factors of destruction are there, and the effect is most prostrating. They are deadly, because they rob the plants of their

water supply and leave them to die of thirst and famine.

Air as a Physiographic Agent. Wind shows surprising power. It sweeps up and down the river valleys, picks up loosened rock particles and moves them along. If they are fine, they are lifted into the air and carried miles before being dropped; if coarser, they are transported only a few rods. Wind rolls pebbles forward until lodged in hollows from which it can no longer move them.

Fig. 7. Sand dunes on Minnesota Point, Duluth. The finer sand grains are assorted out along the beach and drifted land-ward by the winds, overwhelming entire plant populations in their course.
Photograph by A. S. Williams.

Sand dunes occur all over the state, usually not distinguished without a practiced eye, but when once recognized, found literally by the hundred in many a county. The region between Anoka and White Bear is literally filled with sand dunes as the map of the district shows.

The accompanying sketch, copied from the Anoka quadrangle of the United States Topographic Survey, shows numerous low mounds standing a few feet above the marshes along Coon creek. The vegetation covering these mounds consists of a few species of long-rooted plants and the substance composing them is a fine, evenly textured, brownish gray sand that was accumulated by the wind some thousands of years ago. The time must have been before swamp vegetation covered the ground and held in place the drifting sand piles.

Fig. 8. Sand dunes of northeastern Anoka county. They are no longer in drifting stage. Near the middle of the picture the road crosses the marsh by winding from one sand dune to another.

When the rocks are hard, they are polished by wind-blown sand as a sand blast polishes glass or metal. The rocks at Pipestone show beautiful examples of wind polishing.

Practical Notes. Light comes to the eye through the air. The sun shines; that is, there is radiated from it a series of extremely rapid waves of ether. When the earth's atmosphere is reached by a number of these waves, the light is diffused in a most remarkable manner. When clouds intervene it is still light, and even at midnight with this part of the globe turned completely away from the sun it is not totally dark. Short rays are more readily diffused than long ones; so the blue rays which are short as compared with the red and yellow, seem to be everywhere. When there are fewest dust particles in the air, its color is deepest blue. Hence far out on the prairies and over the forests, after a storm has washed the air clean, the sky is beautifully blue. After dust storms the sky looks yellow; when smoke fills the air, it is brassy; toward sunset, it is red from the vapor the sun's rays pass through as they skim along close to the surface for hundreds of miles before reaching the observer.

Considered as an article of food air should be pure. An average adult inhales 360 cubic feet of air every twenty-four hours but takes of liquid and solid food only five and one-half pints. That the gaseous food is 3,000 times more in bulk than the liquid and solid combined should cause great care to maintain its highest possible purity. The many minerals of rock-surfaces disintegrated and carried hundreds of miles exert little appreciable injury; on the other hand organic matter rising up from water-surfaces and moist ground and emanating from scores of towns is deadly and must be guarded against in every possible way.

CHAPTER IV.

RAIN, SNOW AND HAIL.

Source of the rain—Clouds—Why it rains—Rainfall in Minnesota—Reading the map—Some things meant by these figures--Snow—Structure of a snowflake—Hailstones—Structure of hailstones—Prevention of hail.

THE MOST UNCERTAIN thing in the cycle of Minnesota weather is the rain. Its distribution is full of anomalies. We are never sure of its coming until it is upon us, and then we know not how long it is to last. One year it is so dry in June that want follows the plow; the next, so wet that seeds rot in the ground. One day the rain in great drops is driven before a terrific wind; on another it literally oozes out of a still, over-saturated air, to become a visible and soaking mist. One day will bring a dangerous thunderstorm and downpour of rain; another affords a few lone drops to cheer and then to disappoint.

Source of the Rain. One of the constituents of the atmosphere is vapor. When the temperature is lowered, only a part of this vapor can be held; that which cannot be held is condensed into extremely small drops. These drops remain of nearly stationary size and float through the air, buoyed up and moved hither and thither by the shifting winds, forming the beautiful

and useful clouds so characteristic of central North America.

Clouds are truly floating reservoirs. They are among the most interesting objects in nature. Carrying millions upon millions of gallons of water, they float so easily that we utterly fail to catch their real efficiency. One difference between vapor and clouds is the visibility of the latter; between clouds and rain,

Fig. 9. Cumulus clouds and their associates. Forming on the Minnesota prairies they are swept eastward across the Mississippi valley.
Photograph by H. F. Nachtrieb.

the size of the drops. We associate rain with clouds, yet not all clouds yield rain. There are fair weather clouds, like the cumulus, and the makerel sky. These are seen on more days of the year in Minnesota than are rain clouds. In the year 1900, the Weather Bureau says, there were 153 clear days in the entire state, and only 83 days during which rain fell.

Of the remaining 129 days 20 were almost wholly cloudy without rain, and 109 were partly cloudy, that

is, they showed clouds in the sky from 4-10 to 7-10 of the day. These for the most part, we conclude, were fair weather clouds. There are other clouds, like the shapeless rain cloud we call nimbus. This hovers near the earth and is an overload of moisture.

Why it Rains. When the air is cooled so sharply that it no longer holds up the load of vapor the steaming earth has imposed upon it, it rains. Rain may first exist as clouds, or it may not; when the cooling of the air is sudden, cloud-floating is of very short duration, if it may be said to occur at all. The transition is so emphatic as to leave no stage between the invisible vapor and the raindrops thousands of times larger.

Fig. 10. Cumulo-nimbus clouds with distant thunderstorm passing by.
Photograph by H. F. Nachtrieb.

The conversion of vapor into rain is brought about in two or three ways: Gusts of wind may inject currents of cold air into a mass of warm atmosphere; a body of warm air may be lifted into a higher and colder zone; high pressure may bear down one zone into another of different temperature. The great sweep of the prairies and the vast tracts of nearly level forests in Minnesota make possible many interesting phenomena. Standing upon the prairies one may see the onward march of a sudden rainstorm, feel its enveloping presence, and watch its movement when it has gone by. In the forest one is surprised to see in many a storm that the tops of the trees reach into the zone of the rain-bearing nimbus clouds.

Rainfall in Minnesota. The Weather Bureau of the government has organized an excellent corps of observers in Minnesota. Some of them are volunteers who have furnished statistics of rainfall and other weather phenomena for many years. William Cheney of Minneapolis is in the lead with nearly 40 years of almost uninterrupted reports. Sixty-six stations now report to the Section Director in Minneapolis. An examination of the tabulated reports of these stations for the past five years brings out many interesting facts, some of which are summarized on the accompanying map. The annual average for the state for these five years is 28 inches. If the state be quartered through lake Mille Lacs as a centre, the average rainfall for the northwest quarter is 26.20 inches; for the southwest quarter, 27.21 inches; for the northeast quarter, 30.04 inches and for the southeast quarter, 29.94 inches. The station showing the greatest annual average for the five years is Caledonia with 33.70 inches. Two Harbors with 33.32 inches is a close second. The least rainfall is 19

inches at St. Vincent, while Fergus Falls gives an average of 21.93 inches. These figures include the snowfall also.

Reading the Map. Comparing the reading of the 35 Weather Bureau stations on the map it is observed that the western half of the state has an average 3.3 less than the eastern half; the northern, (27.57) but .9 inch less than the southern, (28.27 inches). The highest rainfall occurs in the southeastern corner, an area which lies in the typical prairie region of the continent. The next highest fall is at the shore of Lake Superior and along the iron ranges. The least amount recorded is in the great lake plain of the Red River valley and the next smallest at Fergus Falls in the heart of the Leaf Hills. In physiographic districts, the gorge of the Mississippi-Minnesota shows, next to the Red River valley, the least rainfall— the average of the gorge being 24.84 inches,—while the Red River valley shows an average of 22.66 inches. A careful comparison of prairies and forest areas shows no appreciable variation in either from the normal conditions incident to latitude, longitude, elevation above the sea, and other physiographic conditions.

Some Things Meant by These Figures. Are we aware what these figures mean? With 30 inches of rain, the annual average for the eastern half of the state, falling during 83 rainy days, 36-100 of an inch was the average for each rainy day. Water of this thickness over one square mile would weigh over 27,556 tons. This is enough to load 30 freight trains of 30 cars each, and each car loaded with 30 tons of water. When we multiply this freight by 83 and then remember that the state covers 84,287 square miles, we are glad there are rivers to carry a part of the rainfall to

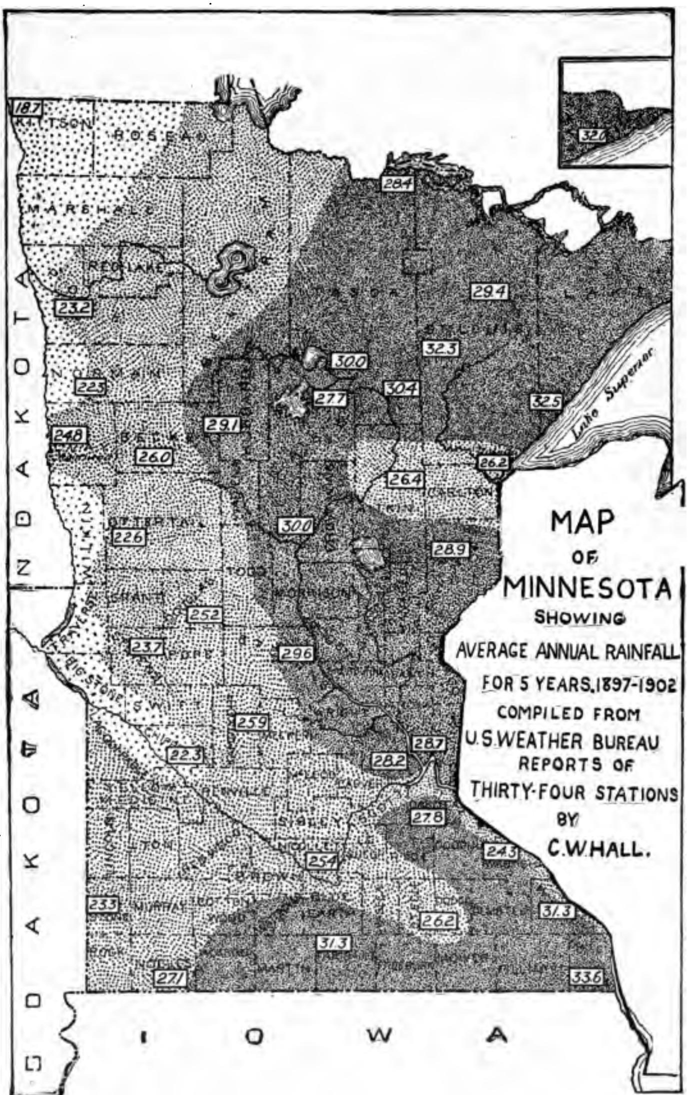

Plate III. The annual average rainfall for the state for the last five years is a fraction over 28 inches. See page 23.

the sea. Again, we are astonished when we think that about 10 inches of this rainfall is quietly taken up again into the air by the process we call evaporation, and that the invisible atmosphere can carry so many millions of tons of water with such perfet case. There are other ways in which this rainfall is disposed of, at once practical and of vast economic value to the farm.

Snow. The question of rain or snow in Minnesota is chiefly one of temperature. Altitude is not sufficiently great to become an important factor. If a temperature below 32° exist, it snows; if above, it rains. The average temperature of the state for December, January, and February is 12.93°. The reason for expecting snow rather than rain during that time is therefore evident. The average of 53.42° temperature from March to November is equally patent for the other three-quarters of the year, and explains why snow cannot fall as the chief form of precipitated moisture.

Still, it is no unusual experience to see a severe snow storm in March, April, or October. In the summer months, solid rain is in the form of hail. Such storms are caused by an unusual cooling of some layer of air and the falling of the collected moisture before it can be melted in its passage through the warmer layers beneath.

Structure of a Snowflake. A snowflake is a beautiful creation. It is symmetrical from its minutest beginnings. The hexagon, or the six-rayed star, is its unit of symmetry. Whenever it branches out, its rays stand at an angle of 60° to the arms from which they grow. A flake is made up of many individuals thus fitted together, yet there always is order in the fitting. Starting as a single crystal it becomes a multitude of crystal forms. The fluffiness of the flakes makes them so light that

the slight puff of a contrary breeze sends them flying upward or sidewise in most graceful curves. They are so delicate that gravitation has but slight effect upon them; yet the crystallizing force in nature holds absolute control in determining their shape and structure. Ice particles possess poles as Tyndall says, that attract and repel, but the attractive poles are rigidly locked together.

Fig. 11. A snow crystal. "The six-rayed star is its unit of symmetry."
Photograph by W. A. Bentley.

When heat is applied, and the ice is melted, these poles stand so far apart that they no longer control each other; so water flows. Yet some time we may learn that water has a symmetry unthought of while we study it as a type of formless matter.

Fig. 12. A snow crystal.
Photograph by W. A. Bentley.

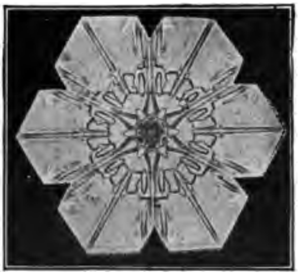

Fig. 13. A more compact snow crystal.
Photograph by W. A. Bentley.

Snowstorms are helpful. A layer of snow protects the ground from intense cold. The grasses and winter crops, when well covered do not feel the blizzards of midwinter. Birds and animals dive into the snow and are comfortable when the mercury freezes

above them. Minnesota plants and animals are adjusted to withstand cold and frost. Many animals retreat into burrows, and many plants move their sap supply into their roots and, thus snugly underground, escape extremes of temperature. This escape is the more absolute when a thick layer of snow covers the ground.

Mr. W. A. Bentley of Jericho, Vermont, is a zealous student of snow crystals. From a number of photographs presented to the writer those pictured above are selected as typical. Mr. Bentley has taken over 800 photographs of snow crystals and no two of them are alike. This is evidence of the wonderful diversity of form possible within single symmetrical groups. In a favorable snow storm one can catch flakes upon the sleeve and with an ordinary pocket magnifyer see just as beautiful crystal forms as those here figured.

Hailstorms. Storms of rain and snow are beneficent to every one; but a well-equipped hailstorm brings destruction. When hailstones fall, broken windows are but a small part of the damage; beaten-down grain fields, injured stock, dead birds, and destruction of every sort, are looked for by farmers who know too well the character of these storms. The yearly loss from hail in Minnesota amounts to hundreds of thousands of dollars. Woe to the farmer who chances to live in the path of the hail! No help can reach him —his hope lies in the mildness of the storm.

Fig. 14. Cross section of a hailstone. Partly diagrammatic.

Structure of Hailstones. Hailstones are interesting objects. Every school boy has cut them open and found therein both snow and ice; usually the latter forms the centre, and then snow and ice in alternate layers to the outside, the outer layer one of ice. If the hailstone be a large one, as large as an English walnut or an egg, these alternating layers are several in number.

A radial structure is frequent, showing that the force of crystallization is powerful enough to arrange the molecules of snow and ice in a very orderly and symmetrical way as they become attached layer after layer around the central mass. Just how the concentric habit of the hailstone is produced is not clearly understood. It is believed that the pellets are driven hither and thither by diverse currents of air, some warm, some cold, and not allowed to fall directly to the earth as they are formed. The colder currents collect about them additional masses of snow and the warmer ones convert it into ice. Several successive current changes will form as many separate layers in the hailstone. The more violent the storm, the larger the hailstones are.

Prevention of Hail. The utter destruction that so frequently follows hailstorms has caused many efforts to prevent these calamities. All countries subject to them have carried on investigations. So far they have been unavailing. The firing of cannon will not dissipate the storm nor shake in any effective degree the gathering of the elements for destructive work. Any one, it would seem, can prove the probable futility of such efforts to his own satisfaction. Let one sit down and calculate the energy set free in the explosion of a charge, or many charges, of gunpowder or nitro glycerine and compare it with a fair estimate of the energy exhibited in a vigorous hailstorm. The result must be to discourage hope in the attempts in man's small way to destroy the storm movements of the atmosphere.

Practical Notes. Many things can be said about the beneficence of rainfall, but only two will be. Without rainfall all agricultural conditions as we understand them would be completely changed. The deposition of moisture from the atmosphere without the formation

of perceptible drops would maintain plant and animal life, but a very different fauna and flora would occupy the state from those now dominant. Striking physiological differences would certainly prevail.

Fig. 15. Material washed from the air by the rain, July 18, 1902.

Again, rain washes the atmosphere to a most refreshing cleanness. In dry weather there rises from the ground such a load of impurities that the air is very unsanitary. Drops of rain wash out these impurities and make the air again wholesome. The evaporation of the first drops of rain easily gathered after a few dry days is indeed surprising in its results.

Figure 15 shows, greatly magnified, a few of the objects collected in a half cupful of water. Over the numeral 1 are unicellular plants and pollen grains, as of the pine; over 2 are fiber cells and plant spines and over 3 particles of soot and dust-like fragments of minerals.

CHAPTER V.

THE WEATHER MAP.

What the map contains—How constructed—Storm areas—Wind and storm areas—Pressure gradient.

DAILY THERE IS ISSUED by the government weather bureau a map of the United States giving the weather conditions of the day in every part of the domain. This map appears simultaneously from nearly all the section headquarters of the service between the Atlantic and Pacific. It is sent to thousands of postoffices, hotels, manufacturing establishments, railway offices, schools and homes, carrying the facts and forecasts of the day.

Minnesota can readily be outlined and the weather conditions for it and adjoining states can be read. The best way to learn how to read is first to make a weather map of the state. The making will give practice sufficient to enable one to read the weather conditions of the entire state at a glance.

What the Map Contains. Five distinct features of the weather are portrayed on the map: Temperature, atmospheric pressure, direction of wind, precipitation areas and location of storms. From the symbols of these conditions the forecaster states what the weather

Plate IV. The weather map for Saturday, June 28, 1902. Forecast for Minnesota: "Threatening to-night and Sunday, with probably showers."

will probably be in the several sections of the country during the coming twenty-four hours.

How Constructed. The temperature of each station throughout the United States is known at the office of the weather bureau through the reports sent in. From these figures, isotherms are drawn. They are dotted lines connecting stations reporting the same temperature, and usually are 10° apart. The isotherms stretch across the continent often making great curves as any given area is warmer or colder than that to the east or west of it. In winter the curves bend upward on both ocean borders and in summer great curves bend upward in the Mississippi valley and Rocky Mountain region. Isotherms bring out very strikingly the "continental" character of the weather of central North America.

Next, the reports are inspected for areas of low pressure, or cyclone areas. When these are located, continuous lines called isobars are drawn around them heavier than those denoting the isotherms. Outside the first lines others are drawn uniting stations of equal, but higher pressure. Other stations are selected where the pressure is highest, and concentric lines are drawn as before. It thus happens that two or more areas of of low pressure are usually found at the same time in different parts of the country. Between the two or more series of circles are frequently seen lines not continuous, or whose circumference would extend, if drawn, far out of the area of the United States.

The direction of the wind is then placed upon the chart by making a circle around each station and drawing across it an arrow pointing in the direction the wind is blowing.

Cloudiness is indicated by symbols. Partly cloudy weather is denoted by shading one-half the circle

crossed by the wind arrow. Total cloudiness by entirely shading the circle. Precipitation areas are denoted by a series of parallel vertical lines shading the area visited by storms. Sometimes the character of the storm is given by placing within the small circles just described the letter R, rain, S, snow, M, if report is missing, and a zigzag line if a thunderstorm.

Storm Areas. From day to day the areas of cloudiness and storms are most closely associated with the front of the cyclonic area, the area marked "low". This is because the warm air blowing northward and

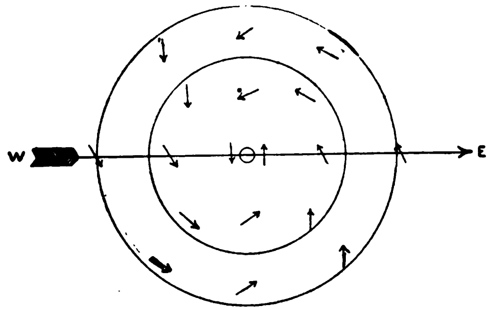

Fig. 16. Diagram of a low-pressure area, a cyclone. The arrows point with the direction of the wind.

inward towards its center along the front is cooled thereby and its moisture condensed. This accounts for the haziness that soon comes when the wind veers to the east and the precipitation that accompanies efficient cooling.

Fair weather is associated with the regions marked "high". This is due to temperature as before; but the air moves from a cooler region to a warmer one, and hence its capacity for moisture increases with its progress.

Wind and Storm Areas. The "high" and "low" areas are closely related to the direction of the winds as indicated by the arrows on the map. The winds always blow toward the "lows" and away from the "highs". An area of low is within a circle marked with some number less than 30, say 29.8 or 29.5. Around the circumference of this vast area the air moves inward

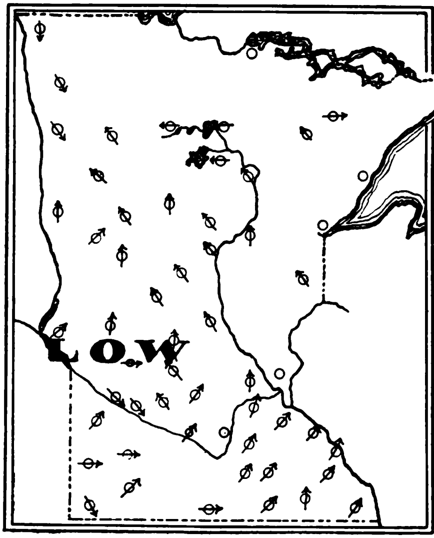

Fig. 17. Cyclone map of Minnesota compiled from the reports of stations for March 15, 1902. The "low" in the west central portion of the state controls the general direction of the wind.

and upward, varied now and then by some minor phenomenon of local extent. This, in its most terrific form, is the tornado.

Indications of wind within a cyclone area are given in figures 16 and 17. In the former the general conditions of wind directions are presented by means of arrows pointing with the wind. In the latter the reports

of the wind sent to the section director by the observers

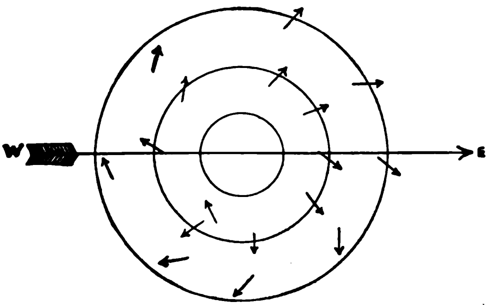

Fig. 18. Diagram of a high-pressure area, an anti-cyclone. Arrows Indicate wind directions, as in figure 16.

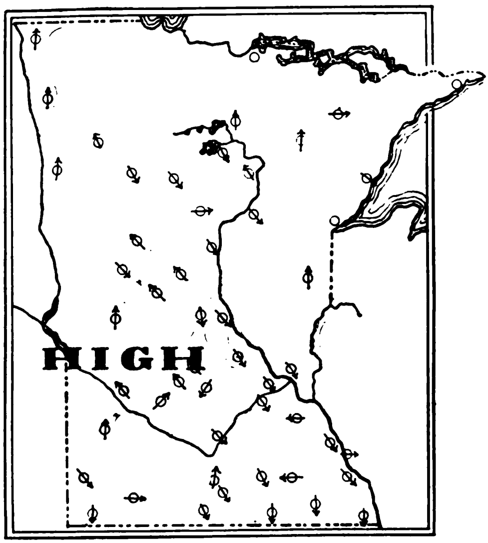

Fig. 19. An anti-cyclone in Minnesota. Wind directions reported for January 3, 1902.

of the state are platted. The weather map of the day

showed a "low" central over western Minnesota, having a barometric pressure of 29.3. A general conformity of the arrows of the two figures is seen; still there are a few minor air-eddies shown which are due to local causes, probably of a topographic nature.

Again figures 18 and 19 present general and specific conditions of an anti-cyclone. The former is a picture as generally shown in the books while the latter is the condition actually reported for Minnesota January 3, 1902, when the barometer indicated 30.8. One is ideal, the other real.

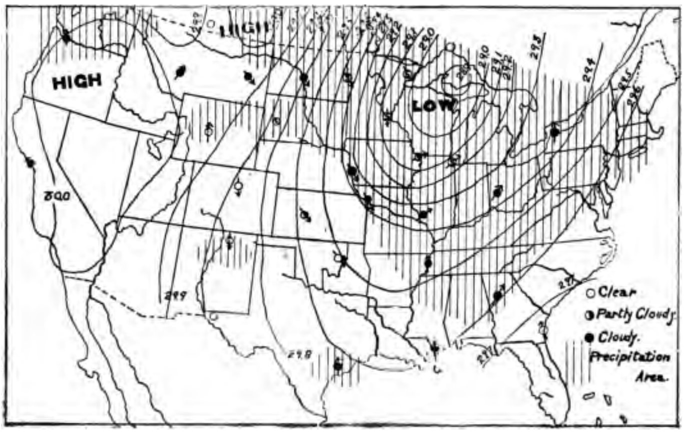

Fig. 20. Pressure gradient illustrated. From a U. S. weather map.

Pressure Gradient. There is a close relation between the distance apart of the isobars and the rate of the wind. When the isobars are near together, the change from one pressure unit to the next, usually one-tenth of an inch, takes place within a very short distance. This causes a violent disturbance of the air by making a steep gradient of pressure along which the wind slides

with a velocity depending upon the rate of the slope, just as a river flows towards the sea at a rate proportional to the steepness of its descent.

An illustration of the pressure gradient is seen in figure 20 taken from a recent weather map. High in northeastern Montana is 30. Low in northeastern Minnesota is 29. This difference of one inch in the height of the mercury column in these two localities 700 miles apart means that on every piece of ground the size of the school room spoken of in chapter III the air is over 60,000 pounds heavier in the Montana than in the Minnesota area. As we think of the pressure per acre and square mile which this computation shows, we do not wonder the wind blew eastward across Minnesota at the rate of 40 miles an hour on that day in its escape from under such a weight of overlying atmosphere.

Usually the differences in pressure are slight. The air moves with gentle current in both cyclonic and anti-cyclonic areas. Such was the case June 28, 1902, the day mapped in plate IV; the report for Minnesota stations was light winds, except Duluth, where a velocity of eighty miles an hour was registered.

CHARTER VI.

THE WEATHER.

The weather—Minnesota weather—Cyclonic weather—A cyclone—The observer's position—Tornadoes—Blizzards—Advent of a storm—Thunder storms.

WEATHER IS THE CONDITION of the air and ground for any particular day or longer period of time. It has reference to temperature, moisture, winds and clouds; yet adjectives from other words than those are often used to describe the weather about which we talk.

The Weather. Minnesota air is prevailingly dry. In moisture it averages much less than that of New Orleans and Vicksburg. While this is determined by the records of the places, yet these are scarcely necessary. Every housekeeper knows that clothes dry much faster on some fair Mondays than on other fair Mondays. An observing boy or girl can prove that the wet hand feels cooler on some warm days than on others. But to make the observation, the observer hangs up two thermometers side by side, one bulb covered with a cloth kept wet, and the other bulb dry. The mercury drops several degrees lower in the wet-bulb themometer. A table called a table of relative humidity enables him to determine by a series of per-

centages from 0% to 100% dry air which, by the way, never occcurs, moist air, and perfectly saturated air. A month's observations in any locality compared with observations of the same month at another locality will give very interesting results.

Both weather and climate are guaged by the standard of human health and comfort.

Minnesota Weather. There are points on which opinion seems to be crystallized touching Minnesota weather. Because the state is far from the sea and relatively low in relief and altitude, its rainfall is small. It is more than that of Nebraska and the Dakotas; it

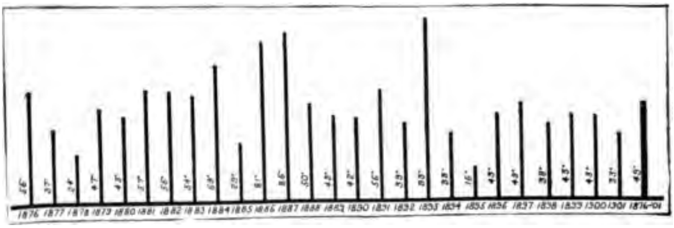

Fig. 21. Snowfall chart for Minneapolis. Prepared from the records of William Cheney from 1876 to 1901, with the average fall for 26 years.

is less than that of any other state east of the Mississippi river, Wisconsin being next lowest. Its central position places it within the belt of prevailing westerlies and in the path of the cyclones that sweep across the continent towards the east. It is on the northern border of the tornado area of the Mississippi valley, only a few of these storms having visited the state since its settlement. Winter moisture, like that of summer, is slight. Snowfall averages only 49 inches at Minneapolis, an equivalent of only 4.9 inches of rain. The amount is less toward the west.

The state is so large that the same weather may not

prevail over its entire area; it may rain heavily in one part of the state and be fair in another. A cold wave may be an entire day in moving down from Saint Vincent to Winona. A hot wind blasting the fields of southwestern Minnesota never reaches Duluth and the Iron ranges. Hailstorms are only a fraction of a mile wide and a few miles long. Thunder showers, to refresh a considerable portion of the state must form and re-form repeatedly.

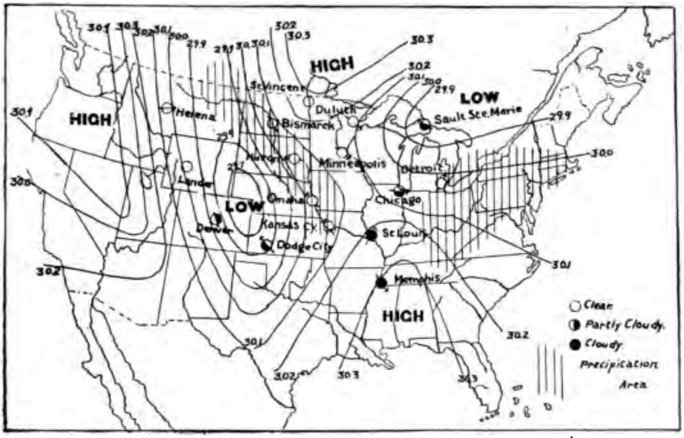

Fig. 22. A cyclonic area with precipitation area along its front. Copied from U. S. weather map for Dec. 18, 1901. "Each storm * * has moist warm air on its east side and cold dry air on its west side."

Cyclonic Weather. Broadly stated, all Minnesota weather is cyclonic. With the continuous procession of "lows" and "highs," on more vigorous march in winter than in summer, crossing the state one after another, the atmosphere is at all times either airily moving upwards in its spiral way, or is being borne down heavily to the earth. Still, there are certain conditions which will guide very accurately in foretel-

ling a storm or its clearing off. The contact of a low against a high brings warmer and more saturated air against that which is colder; condensation must result, and first haze, and then cloudiness follow. The mercury in the barometer is steadily sinking as the center of the cyclone approaches the state. Rain must be expected, although whether it falls at that particular spot is determined by the position of the center of the "low"—whether it be passing directly over the place or to one side. Should the air be unnaturally warm and so still that it grows warmer instead of mixing with neighboring, and especially overlying cold air, violence and disaster may be looked for as the climax of the conditions. "Each storm, then, has moist, warm air on its east side and cold dry air on its west side; so that rain and cold wave move together across the country, two halves of a single thing."

A Cyclone is a great area of low atmospheric pressure, usually hundreds of miles across and many thousands of square miles in extent with the lowest pressure in the center. The cyclone is a vast inward and upward whirl of air. The name was given when it was thought that the wind blew around a center in a circle. It is now known that the wind blows in towards the center spirally in a direction opposite to that through which the hands of a watch move. Yet wind never increases the pressure enough to break up the cyclone, because the air thus brought into the area moves upward and, at considerable distance above the ground, becomes distributed again. The air pressure is thus equalized.

The cyclone is probably an eddy in the great circum-polar whirl as the air moves round the hemisphere in ceaseless motion. In its first elements it is an area

in which winds have a certain unity of motion and relationship in origin, thereby displaying a grandeur and effectiveness at which we marvel. The cyclone moves along at the rate of an express train. For Minnesota it forms on the Pacific coast or in the Rocky Mountain region. We recognize its position because its center is an area of low barometric pressure, that is, of light air. Its thickness is probably not more than two or

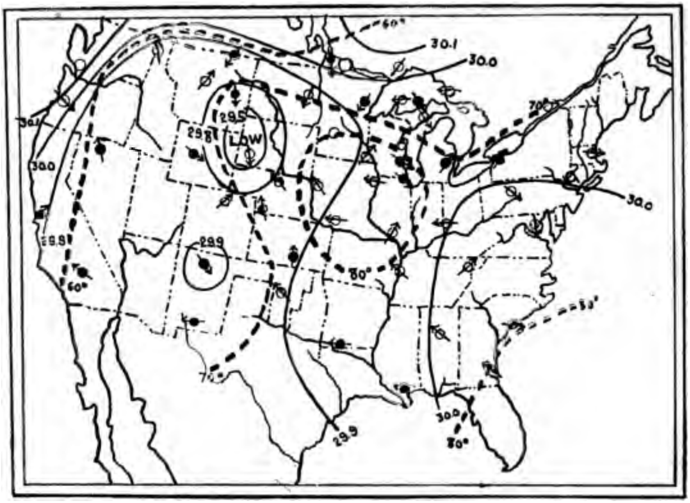

Fig. 23. A cyclonic area on a hot day, July 24, 1901. Temperature at Minneapolis, 101°. For several days in succession the area of low pressure hung to the western edge of the great plains, producing over Minnesota hot southerly to southwesterly winds.

three miles, at which height the air currents are accelerated into rapidly moving masses directed eastward around the globe. Updraft therefore soon brings the surface air to a cooler zone. Storms follow as a matter of course:— rains in summer and snows in winter are sure to come; they are the forerunners of cyclones. But cyclones are very harmless things.

The Observer's Position. To study the advance of a cyclone, and at the same time note its effect, one must determine one's own position with reference to the cyclonic center. If it be south of the line traversed by the center, the wind is first east and southeast; then south and southwest; at last west. If north, then the winds are blowing southwards through two quadrants of the circle.

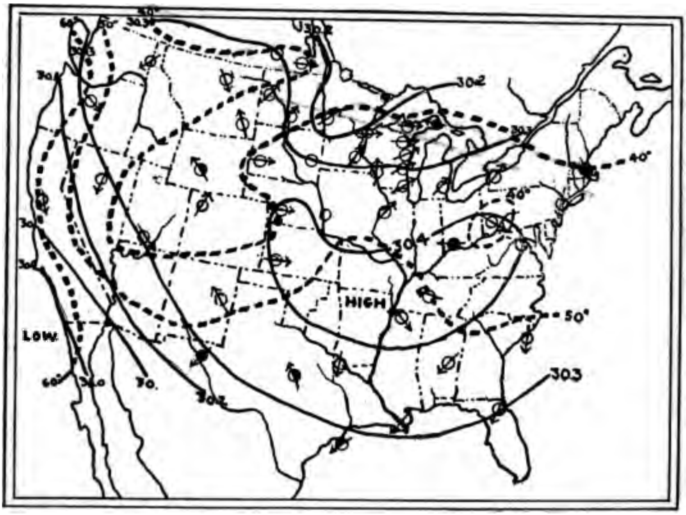

Fig. 24. An ideal autumn day. High pressure over the central Mississippi valley. Date, Oct. 21, 1901. Temperature in Minnesota around 70°.

Practice will enable one to locate quite accurately the center of the cyclonic area by the direction of the wind; provided the direction for the preceding few hours be observed.

Every storm area or cyclone has a moist, warm side *first* and a clear, cold side last.

Prevailing Westerlies. Occasional though they are, the prevailing winds come in a continuous succession of cyclones and anti-cyclones sweeping across the continent from west to east. They may be at times irregular in their direction or rate of progress. Were it not the case, we should experience a monotonous alternation of stormy and pleasant days, of warm and cold, of relaxing and invigorating ones.

Storms. In common use, the word storm means a condition of the air which is accompanied by rain or snow. Yet there are wind storms, dust storms, and thunder storms without rain or snow. Storms indicate some special movement of the atmosphere; not any movement, for the air is always in motion. Storms are local disturbances incident to the march of a great cyclone in its continental progress. At all times of sufficient moment to attract attention, frequently a storm commands solicitude.

There are times when the sky quickly darkens and the rain pours down inches per hour; we liken such storms to the cloud-bursts of the Basin region. We sometimes call them cloud-bursts. The wind at rare intervals sweeps over small districts with irresistible violence, carrying almost everything away, killing man and beast when so unfortunate as to stand in its path; we sometimes call these calamities tornadoes, yet they are only wind storms. In winter there are storms that advance like hurricanes, bringing furious snow and intense cold in their train; they are pitiless upon those who are caught unprotected, and many a herd has been thinned before them. These are called blizzards.

Thus it is that the word storm is applied to the ordinary everyday occurrences in weather-phenomena.

Whenever a greater event takes place, a larger name is given it, that due importance may be attached to its coming.

Tornadoes. The tornado is the type of a very common kind of storm, but it is the type of its most terrific phase. The dust-whirls of fields and street corners and the sand-storms of the prairies and plains command only passing attention. But when the force and destructiveness of the tornado are attained, all nature is awed and overcome. It seems as if all the energy

Fig. 25. The destructive lake Gervias tornado, near Saint Paul, July 13, 1890.
Photograph by William F. Koester.

of the great cyclone area were concentrated into a mile or two. Thunder and lightning accompany tornadoes. The air circles and ascends in currents irresistible by everything save the solid earth. The speed of the air-current cannot be less than one hundred miles an hour and it may be a thousand. The height reached by the air thus violently in motion is rarely or never more than half a mile and the funnel composed of whirling clouds and dust and flying things is not more than a thousand feet long.

Rotatory Storms of small extent, that is, those which cannot be regarded as cyclones, occur the world over, but that type we call tornado does not. The Mississippi valley is peculiarly subject to these. Minnesota appears to lie on the northern boundary of the tornado area. A number are recorded for the southern half of the state, some of them appallingly destructive, but the northern part of the state is very free from their visits. While occasionally they occur in April and July, May and June are the usual months when they come and some years pass with but little or no loss from their occurrence. At Waterville five funnels were seen within two hours of a single day, but not one of them stooped to the earth for destruction.

"**Clearing Off.**" As the cyclone moves forward, the center of the storm passes steadily east-northeastward. It passes the observer and the weather is felt to change. Soon comes the "clearing-off" shower. It is thus close because the center of the storm is always pushed ahead of the cyclone center. The wind during the last hours of rain or showers blows from the west. The moisture is driven away to the eastward, and fair and cooler weather comes on with the back side of the storm. It is cooler because the air comes from the mountains and across the great plains, from the northern part of the cyclone area.

We thus have cloudy weather, storm, clearing-off and fair weather following each other in steady succession throughout each season year after year. The government weather service has revealed much concerning the great continental air movements.

Blizzards are storms in which a high, cold wind is accompanied by blinding snow. They express the severe winter phase of the cool, vigorous clearing-off

storm of the summer months. They seem to be peculiar to the northwestern states, or within the region affected climatically by the northern Rocky Mountains, and are an extreme form of the cold wave, accompanied by snow. Sometimes after the clearing off it is "too cold to snow"; exceptionally it does snow, and the severe cold wave becomes a blizzard.

Advent of a Storm. West winds indicate fair weather; southwest, warm days; northwest, fresh and cool air. The westerly is the natural planetary wind of the latitude.

A southeasterly wind indicates an approaching cyclone. Clouds follow a decidedly hazy appearance of the eastern sky. These represent the undeposited moisture made visible through the cooling and condensation of the air currents ascending farther eastward. In other words, cloudiness is an evidence of rising and cooling air-currents in the region where clouds are being formed. In a day—more or less, according to the rate at which the cyclone moves—rain comes. Its place is on the southeast side of the great cyclone area, because the whirl of the air brings the condensed moisture of the cyclone to this side before precipitation takes place.

Thunder Storms. Every cyclone may be accompanied at some part of its area by "secondary storms." These are local, each one traveling only a few miles and then giving place to other weather conditions. These in turn are modified as the cyclone advances on its course.

The secondary storms of most interest are the thunder storm and the tornado.

The thunder storm is the child of the tropics. When it occurs in Minnesota, tropical conditions of a

certain type are gathered here. A small cyclone forms, in which the hot air is sucked upwards without the rotary movement of the great cyclone. Electrical phenomena attend the movements of the air, either as cause, effect, or associated energy. The rain of a thunder storm is usually formed within 3,000 feet of the earth's surface. Thunder storms are usually found on the south side of the cyclone. They are preceded by a period when the air is warm, moist, and quite still.

CHAPTER VII.

CLIMATE.

Definition—Minnesota climate—Stability of climatic conditions—Bending of isotherms—Length of day.

CLIMATE IS THE MEAN of weather conditions. While the mean usually pertains to a year, it may be used to describe the somewhat prominent weather conditions of a season, a month, or other division of time. We often speak of the winter climate as cold, clear and bracing; the autumn climate as bright and invigorating. When we speak of a year or a season as unusually cold or warm or wet, we refer it to that average of weather which has given the standard climate from which the given year or season has departed in the respect named. Weather is sometimes the very personification of caprice, but climate is always the type of constancy.

The word climate comes from a classic source, which meant a slope, referring to the supposed slope of the earth polarward from the equator. Ancient geographers accordingly subdivided this "slope" into 30 zones parallel with the equator, each corresponding to an increase of a quarter of an hour in the length of

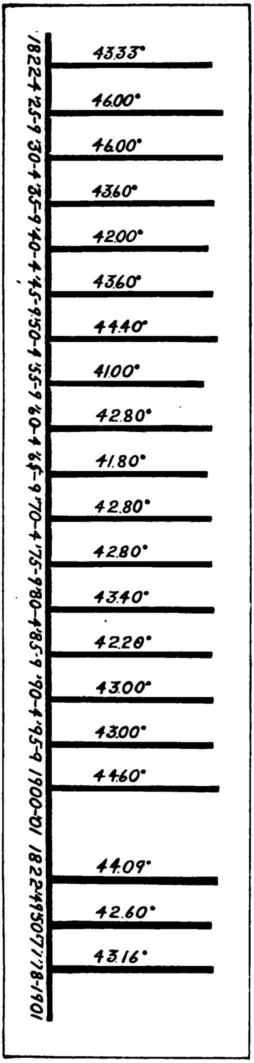

Fig. 26. Diagram of average temperature, compiled from records kept at Fort Snelling and Saint Paul since 1822.

the midsummer day. Our present use of the word is quite different from that ancient one.

Minnesota Climate. Putting now the weather into terms of permanency, we say that Minnesota has a fairly bright and sunny climate. For the last five years the average of sunshiny days is 150. Although Colorado has 340 days of sunshine, Michigan has but 135, and Maine 117. Sunshine carries cheerfulness of spirit; so it conduces to hearty enjoyment and vigorous health. While our hottest days are above 100° in the shade, and the coldest 50° below zero, the average of five years is, for July, 73°; for January, 13.2°, and per annum, 41.9°. This is 1.26° colder than the average of the last 24 years at Minneapolis, as shown in the vertical right-hand line in Fig. 26.

If we compare these figures with those of two or three other states, the results may prove of interest. Weather bureau data show that western Washington in our latitude on the Pacific had in 1901 a temperature of 9° on its coldest day and 101° on its warmest; its average for

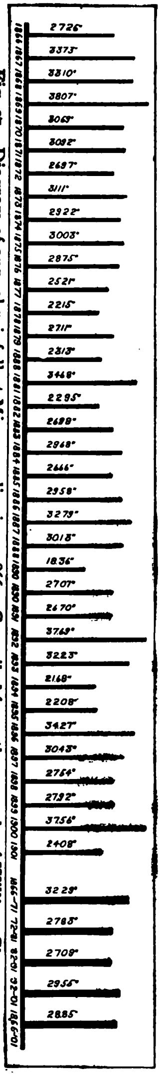

Fig. 27. Diagram of annual rainfall at Minneapolis since 1866. Compiled from the records of William Cheney.

the year is 49°. Maine, on the Atlantic, gives a minimum of 11°, a maximum of 96°, and an average of 45.2°. Michigan, almost a neighber of Minnesota, shows two distinct climatic regions in its Upper and Lower Peninsulas. These two regions differ from each other in some degree and each differs from Minnesota in its climatic averages.

Dryness is another feature of Minnesota climate. While we know that rainy days are few, the stated humidity of the atmosphere is correspondingly slight. Tower is the sunniest spot in the state. Its record of clear days is 213 per year for the last few years. Duluth has more rainy days than any other station, averaging 123; the state as a whole reports only 81. It must here be remembered that often while it is clear in one part of the state, rain is falling in another. This figure is for the entire state. While the figures for neighboring states would be tiresome to compute, it is believed that these given for Minnesota compare favorably with them all.

Stability of Climatic Conditions. It is always asserted that each year is an unusual one, and often that the climate is changing. Figures do not confirm such statements. While there are variations in the rainfall of two successive years, the average of tempera-

ture is much more uniform. 1901 showed an average temperature of 42.8°, and this is 2° above the average for the last five years, and 1.1 below 1900.

Some years ago the Pioneer Fuel Company gathered and published temperature reports for Fort Snelling and Saint Paul, reaching back to 1822. In Fig. 26 these reports are arranged in groups, each group showing the average temperature for five years, the averages being stated in numbers beside vertical proportional lines. Great evenness in the temperatures of these five-year groups is seen.

Again, the seventeen five-year groups are averaged in three groups of 28, 28 and 24 years, respectively, as seen in the three heavier vertical lines at the right end of the figure. The differences there shown are not great; indeed, imperfect record during the first fifty years might cause all the variations the numbers and line-lengths show.

Were we to go still further and average the three heavier columns, the result is 43.29. This is 1.30° higher than the average of the state for the last five years.

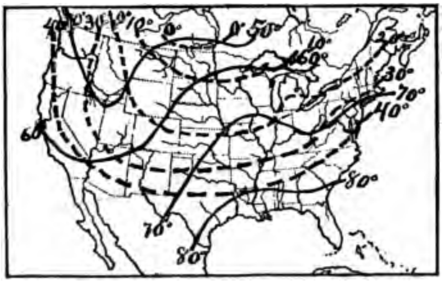

Fig. 28. Map showing continental character of Minnesota climate. Continuous lines are averages of July days; interrupted lines, averages of January days, taken from U. S. Weather Bureau reports.

Temperature conditions depend partly on the length of the day incident to the distance from the equator. We find that the longest day is 15¼ hours on the Iowa border and 16¼ hours long at Lake of the Woods. In December the shortest day is too short to receive much warmth from the slanting rays of the sun. The average temperature for December is near 15.5°.

CHAPTER VIII.

THE STORY OF THE GLACIERS.

Where glaciers occur—North America's ancient glaciers—Cause of the Ice Age—Final decline—The "Driftless Area"—Minnesota in the glacial period—The three invasions—Evidence summarized.

A GLACIER IS A STREAM of ice flowing over the land. The ice springs from the snows that fall. A necessary condition for the existence of a glacier is a temperature so low that the ice does not become water. This condition restricts the ice-stream to certain areas of land which vary in extent from year to year. While a glacier is a stream, it moves with slowness. It transports material, both coarse and fine. It grooves its bed and builds high its boundary walls. The course it follows is marked by such positive characters that the glaciers' track is as readily followed as the path of men.

Where Glaciers Occur. To see a glacier in its grandeur, one must go to Alaska, the Rocky mountains, or Greenland in North America, to Switzerland or Scandinavia in Europe. Other localities are not so widely known. There are still lingering in the Rocky mountain range isolated glaciers which are visited by many tourists. The great glacier of the Selkirks, the *Sperry glacier* of Montana, and a few others, still re-

Fig. 29. The Yoho Glacier. The central feature of this figure is the glacier. The clear massive ice extends backward for many miles: its sources are seen in the snow fields upon the distant mountains. To the right and left the ice-stream is hemmed in by hills in front of which on either side high lateral moraines are pushed up. These carry boulders, pebbles, sand grains and clay; they are long piles of typical till. In the middle of the ice-front a river pours out from beneath the glacier. This, reinforced by the waters formed from the melting ice, carries and assorts the terminal moraine into that mass of stratified material called modified drift.

Thus we see the glacier in the midst of its work, cutting down and transporting the underlying rocks, depositing the same as till or unmodified drift in moraines and as modified drift in the river deposits further down the stream.

Photograph by E. R. Shepard.

main as relics of what was once an enormous expanse of moving ice.

The present great ice-field of the Northern Hemisphere is Greenland. Here are several hundred thousand square miles covered with ice flowing steadily over the island toward the sea. How thick the Greenland ice is, no one knows, but it must measure thousands of feet. In the interior of the island, the hills and mountains are completely covered by ice and the envelope of snow out of which ice is formed. It is only along the shore that rocky summits rise above the ice surface. Descending gradually toward the coast the ice thins out and is pushed into the sea as icebergs, or melts on its southern edge along the warmest part of the island.

North America's Ancient Glaciers. Greenland's ice-field is mentioned because at a period in the not very remote past, Minnesota was the home of glaciers. The entire northern part of North America was once covered with a field of ice larger than that upon Greenland to-day. The southern border of this great ice field has been traced by characters the trained glacialist at once recognizes and reads. Eastward from the Rocky mountains it crossed Montana, the western part of North Dakota, the heart of South Dakota, western Nebraska and Kansas, middle Missouri, southern Illinois and Indiana, northern Kentucky, southern Ohio, Pennsylvania, New York and New Jersey, and, traversing Long Island, continued into the Atlantic. The evidences of this invasion and proofs of the accompanying stage of intense cold are abundant and conclusive. No one who studies this subject candidly doubts the assurance his own eyes give. As one reads the published accounts, the results of years of labor by as well-trained experts as any land can produce in any

field of scientific inquiry, one feels implicit confidence in their trustworthiness.

The underlying rocks of this so-called glaciated area of the continent are polished and scored as rocks are wrought by the glaciers of to-day; long piles of sand, gravel, and mixed clay and sand are seen just like

Fig. 30

those now being made where glaciers leave their debris; ancient lake bottoms and river courses are in clear evidence, bearing all the proofs of their origin from beneath such conditions as prevail in this century in Greenland, Alaska, and the northern Rocky mountains.

Nowhere in all the ice-covered area of the continent are the proofs clearer or the traces of glacial work fresher than within the borders of Minnesota; and nowhere does its presence and distribution exert a more potent influence upon every industry of the commonwealth. For these reasons the glacial drift of the state here receives attention and will be the subject of allusion in about every chapter of this book.

Cause of the Ice Age. Ice Age is the name given to this period of the geographic history of the earth. The strange contrasts it presents, combined with the recency of its occurrence, make it one of the most fascinating subjects of study. Picture oneself, several thousand years ago, standing on the northern boundary of the state. At a height above the sea of not less than 6,500 to 7,000 feet one is in the midst of a sheet of ice stretching northward into the Polar regions and southward to Kansas and southern Illinois, not less than 750 miles, with the Rocky Mountains and Atlantic ocean as its borders. The formation of this ice sheet was due, perhaps, to the uplifting of the land into an enormous inland plateau several thousand feet above the sea. Suppose the state were raised bodily 3,000 feet above its present position, a supposition by no means absurd or improbable as earth movements go, its average annual temperature would be lowered from 41.8° the average of the last five years, to 31.8°, or below the freezing point. Vastly more snow would fall if the state were 4,200 feet above the sea than falls now, making much more to melt away under a longer and colder spring than we now have. Whatever was not carried away in one season would remain until the next, and thus in a few centuries an enormous and expanding sheet of ice would be formed.

Final Decline. We assume an uplift of the continent to cause the Ice Age: We can, with no more offense to sense and judgment, assume a sinking of the land to soften the climate and cause moisture more frequently to fall as rain, and ice to melt away more rapidly than to form. Assume successive oscillations down and up, so slow that thousands of years are consumed in a single movement, and the level would be finally reached that would cause the ground to be laid bare and enable plants to return and occupy the vast plains, prairies, and forests of central North America. After a few thousand years the aspect would be of verdant prairies and magnificent forests precisely as we see to-day, a well-established epoch of world-history.

The Driftless Area. In the midst of this enormous sheet of flowing ice, there stood a tract ten thousand square miles in extent which the ice did not cover. It was like a great island in the midst of sweeping and surging floods. But the mysterious feature of the island is its position, that of a valley lying snugly low between the ice-capped hills on every side. This drift-barren surface lay in four states, Wisconsin, Illinois, Iowa and Minnesota. Within Minnesota are 3,000 square miles that are called driftless. The topography of this region as well as its soil and outer rock features, are so different from those of the rest of Minnesota that they have always commanded attention. At Saint Paul and Hastings there is one type of topography, a glacial soil and underlying sands and gravels; at Winona and LaCresent, a different one, a uniform soil, and no glacial gravels beneath, only decayed and decaying rocks. There are no smoothly rounded mounds in this region to mark the place of glacial moraines, few rounded pebbles against which to stub the toes, no

boulders to turn the plow from its course, and no sloughs as evidence of obstructed drainage. Every feature bears ample proof of age, and shows the results of long continued and steadily operating processes.

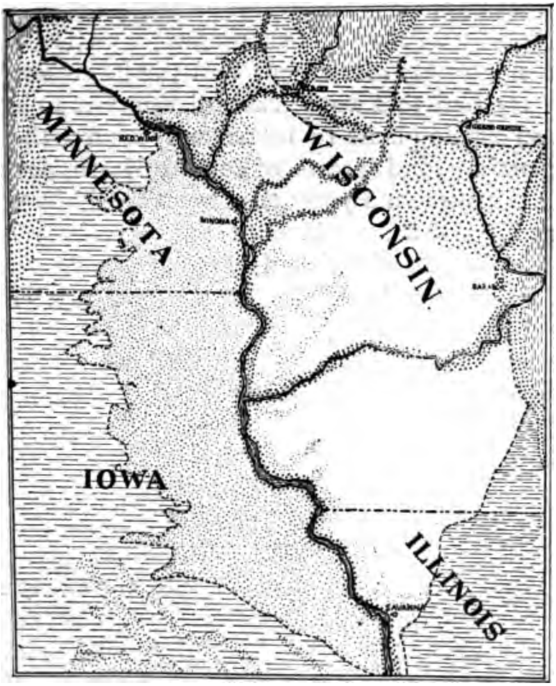

Fig. 31. The Driftless area of Minnesota, Iowa, Illinois and Wisconsin. The portion of Minnesota within the area is shaded to indicate wind-distributed material.
After Chamberlin and Salisbury.

Minnesota in the Glacial Period. Thus it is seen that Minnesota was once ice-covered, save the small tract in the southeastern corner. Nay more, the state *must* have been covered several times with fields of ice,

which as many times were melted away and made to retreat to more northern regions. Some of these periods of retreat must have been long. It is usual to estimate geologic and geographic processes by their results. One of several places in southern Minnesota where the phenomena can be seen, is near Mankato. Here is a tract where, beneath a fairly good covering of glacial drift, lies a bed of peat two feet in thickness. Beneath this peat lies another bed of glacial drift resting upon the underlying rock. In Chisago county, well-diggers find beds of peat between two glacial drift deposits which are quite unlike each other in several particulars. But this question need not be discussed further than to say that there must have been several great ice-invasions, each after pushing forward retreating so far as to produce quite normal temperature conditions in this portion of North America. Naturally the last advances of the ice left traces so marked that the hesitating steps of their retreat can be followed.

It would seem that in the later days of this ice age of Minnesota there were three invasions of glaciers from three different directions, and at about the same time, representing three different sources of supply. First, there was the great glacier from the lake Superior region. The ice flowed in a southwesterly direction. This stream or lobe was hundreds of miles wide for it stretched from beyond Duluth to the neighborhood of Wabasha. It moved into the central part of the state. The evidence of this is the red color of the debris which the glacier left in its retreat. At Duluth one sees nothing but red clay, red sand, red gravel. That is true for many square miles within the eastern part of the state. This red debris is seen in beautiful exposure at Taylors Falls; it is noted in

Minneapolis and Saint Paul where railroad work and other excavations have disclosed glacial deposits. The color arises from the decomposition, continuous throughout many a time-epoch, of enormous masses of volcanic rock poured out during an early period of geologic history when volcanic activity was at its height in the lake Superior basin.

Another stream of ice flowed into the state across the northern border. Rainy lake seems to be the center of this invasion. Large quantities of the most ancient rocks, granites, gneisses, and "greenstones," were torn up, moved forward and deposited as far southward as the headwaters of the Mississippi. There is strong probability that this stream was broader than the state itself; its western boundary possibly rested against the Turtle mountains.

The third great stream entered the state along the Red River valley. Its west bank was in the Dakotas, and its east bank was partially defined by the ice-stream from the region of Rainy lake. This Red River valley stream, doubtless re-inforced from Rainy lake, moved at a stately rate southwards up the present valley, down the valley of the Minnesota river, and over into Iowa, not becoming melted until it had passed Des Moines. Its eastward bank was within the state of Wisconsin, east of Saint Croix Falls and Hudson. It crossed to the west side of the Mississippi in the vicinity of Wabasha, and stretched southward along the western boundary of the Driftless area into the state of Iowa. Along its west side it piled up a mass of glacial debris, the Coteau des Prairies, one of the highland portions of the state.

These three great ice streams long since disappeared. They melted slowly and fitfully northward.

Many times during the retreat they gathered volume and readvanced, pushing boulders, boulderets, pebbles,

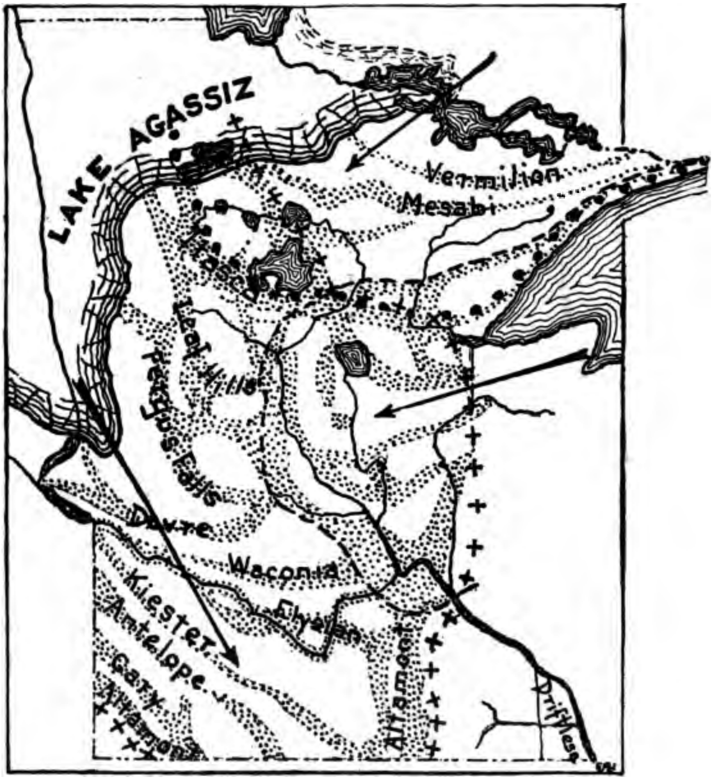

Fig. 32. Glacial map of Minnesota showing the principal moraines of retreat. The chain of crosses represents the approximate boundary of the Red river valley stream, the straight lines that of the Lake Superior lobe and the circles that of the Rainy Lake lobe. Arrows indicate general direction of the ice currents.

and grains of shattered and worn rock masses into the great heaps and long ridges we now call moraines.

Retreating from these piles of debris, the glaciers successively left behind them extensive areas in which water would assort the material and deposit the frequent beds of clay and sand. But milder weather finally drove them back until the only relics which remain of these enormous ice-sheets are the pleasure spots around the Selkirks and in the heart of the Rocky mountains.

An interesting feature of this retreat lies in the numberless lakes formed of melting ice, only to be obliterated as soon as the successive seasons drove the ice front forward, and again re-formed when warmer years caused it to retreat.

Fig. 33. A glaciated rock surface near Tower.
Photograph by F. A. Wildes, Jr.

Summary. It may still be asked: What proofs have we of this whole glacial time? First and universal evidence lies in the deposits of gravel, sand, and clay covering so large a portion of the state. These deposits, compared with those being formed at

the present time in Alaska, Greenland, and the Alps, are found to agree identically with them. Indeed we know of no other way in which such peculiar deposits can be formed. Rivers perform their work in quite a different manner. This fact is seen along any stream, when its partially stratified and somewhat assorted deposits are compared with the boulder-filled banks of gravel, sand and clay called glacial drift.

Again, upon the surface rocks of many an exposure there are deep scorings and slighter scratches made as the glacier current pushed over them the boulders and pebbles carried along in the current. Limestones in Minneapolis and Saint Paul, gneisses in the Minnesota valley, granites in Stearns and Morrison counties, and hundreds of rock exposures in northern and northeastern Minnesota show scored, smoothed and polished surfaces exhibiting identically the same phenomena as are seen at the foot of any Alpine glacier.

Thirdly, the glacial debris, called till, is arranged in such position as to prove its transportation by a stream of ice. So far as observed, in every case this peculiar accumulation could be formed in no other way than by ice action.

CHAPTER IX.

MINNESOTA'S TALE OF THE ICE INVASIONS.

Work of the glacier—Glacial drift—Moraines—The moraines named—Other glacial features—Lakes—Practical comments.

EFFECTS OF GREAT MOVEMENTS, men think, are partly transitory and partly permanent. Could they but perceive how things would be had certain earlier events not occurred, or occurring, had occurred differently, it could be convincingly shown that all effects are permanent. Among the effects clearly permanent are erosion of rock surfaces and the transportation of material. Could men look backward half a million years and see what forest trees towered above the land and what creatures fed upon its herbage or lay in wait for unsuspecting prey within its thickets, all which living things were forced to wander southward for a new home or die of cold with the on-coming of the Ice age, their clearer vision would convince them that physical conditions imposed upon plants and animals are as permanent as when imposed upon rocks and river valleys.

Work of the Glacier. Ice, when pure, can erode but little. While it can carry any debris placed in its way, it is as helpless in erosion as pure water. It is

Fig. 34. A glaciated rock surface, southwestern Minnesota. The glacial drift was so thinly spread that no soil can be formed upon the surface of the red quartzite, the underlying rock.
Photograph by C. B. Hibbard.

only when loaded with rock fragments taken up in its course that it is furnished with an agent of effective work. The rock fragments in the bottom of the ice constitute a cutting tool of remarkable power. The old rocks of Minnesota have been cut down in places perhaps hundreds of feet through the scoring and abrading action of ice loaded with rock pebbles. Certainly the surface of the earlier rocks was smoothed down in a most remarkable way.

That transportation, too, was effected, is seen in every gravel bank within the state. We see not only fragments of the underlying rocks, but pebbles of other rocks not known to lie within hundreds of miles. The extent of transportation, considering the slow, creeping movement of the

ice-stream, is truly remarkable. Doubtless much of the material in the moraines and glacial plains of Iowa was brought thither from Minnesota and possibly even from Wisconsin and Ontario, while much of that within this state has been brought from beyond its northward lying borders. The numerous masses of red till, sand, and clay lying in the eastern part of the state within the area of the lake Superior glacial stream must have been brought from the lake Superior basin. How far within Canada the Rainy lake lobe took up its pebbles of granite and "greenstone" is hard to determine; that they were brought into the central part of Minnesota is clearly evidenced by their existence there in great numbers.

Glacial Drift. "Drift" is the name given to the en-

Fig. 35. A bank of till or unmodified drift near Tower. Typical of morainic material throughout the state.
Photograph by F. A. Wildes, Jr.

tire accumulation of the Ice age, whether the rock-

waste be deposited by ice or ice-water. Both kinds of material are abundant in Minnesota. The total average thickness for the whole state must be 100 feet. It lies in places in great level sheets many miles in extent, while elsewhere a tumultuous succession of mounds and hills marks its surface appearance.

The ice-deposited waste is called boulder clay because it is made up of a fine to coarse, sometimes sandy clay, through which are dispersed boulders of all sizes up to many tons' weight. Other names for this material are "till" and "unmodified drift." Its three characters are: 1, it is unstratified; 2, its fragments are rounded; and 3, much of its material is foreign to the locality where found.

The water-deposited drift is called "modified" because it is modified or assorted just as water would assort

Fig. 36. A bank of modified drift, Kettle river. The stratification of the material is clearly seen.

it in a lake or along a turgid stream. A stratified condition is the chief character by which it is recognized. It lies in level tracts, or seemingly intermingled with

the umodified drift. Where level, it indicates a comparatively rapid retreat of the ice-sheet for a considerable distance, owing to a more or less prolonged period of growing warmth without intervening seasons of so great cold as to cause the ice-stream to push forward again its morainic load. There are many phases of this stratified glacial drift, as kames and sand plains.

Moraines. Ridges of rock waste, long and short, pushed together and left by ice streams as they first advance and then retreat are called moraines. Naturally then they are chiefly made up of unmodified material, or till. They make all the hills we see in many counties of the state. Often they are only knolls standing singly or in belts, stretching away for miles across the prairies or through the forests. Again, they are high and stately ridges rising hundreds of feet above the general level. Such a ridge. or rather, double ridge, is the Coteau des Prairies, crossing southwestern Minnesota as it extends from South Dakota to Iowa. The Coteau with its height, its long green slopes, graceful contours, and hazy distances, was the Shining Mountains of the early explorers traversing western Minnesota. The Leaf hills is another notable morainic region truly wonderful among the physiographic regions of North America. The long belt of knolls, ridges and chains of hills stretching from northern Wisconsin to central Iowa through Chisago, Ramsey. Hennepin, Carver, Scott, Dakota, Rice, LeSueur, Waseca and Freeborn counties, reveals a story of glacial time to him who can read it scarcely paralleled in the history of the continent. Two gigantic ice streams, one from the district northwest, and the other from the Lake Superior basin, crowded one another back and forth repeatedly like two giants, each struggling to push

the other forever off the ground; the northwestern lobe, seemingly the victor, moved on and found, in its front, a new charming valley it could not enter, the Driftless Area.

It would take pages to tell the whole story the moraines can reveal. Every portion of the state has its moraines. They play a most important part where the Mississippi gathers its waters; they conceal unknown bodies of iron ore, and afford the standing-place for the pine. The importance of moraines among the

Fig. 37. A typical morainic landscape in central Minnesota. A scene in the Leaf hills, Otter Tail county.
Photograph by Warren Upham.

surface features of the state may be realized when we consider that they cover more than half its area and doubtless underlie other tracts where, topmost, lies an ancient lake bed or drainage course.

The Moraines Named. Warren Upham has devoted years to the study of glacial geology. Among the many facts pertaining to this epoch of earth history, so much in evidence in Minnesota, worked out by him, the identification of the successive moraines stands out

clearly. The Red River invasion has been traced in its retreat from Iowa to Manitoba and its several read-vances and rest-periods determined. Each one of these is marked by a moraine which can be followed by its long rows of rounded hills, some long, some short, across several counties and in some instances even across the state.

The moraines are thus named, the first three by Professor Chamberlin, the others by Mr. Upham: In reading these descriptions consult figure 32 in the preceding chapter.

1. *Altamont*, stretching from Altamont, South Dakota, across the south-west corner of the state. It forms the outermost (southwesternmost) crest of the Coteau des Prairies from Shaokatan to lake Ocheeda.

2. *Gary*, forming the inner crest of the Coteau from Gary to Spirit lake.

3. *Antelope*, extending from Antelope hills, Lac qui Parle county, south-eastward past East Chain lake into Iowa.

4. *Kiester*, in its finest development in the Kiester hills of Faribault county.

5. *Elysian*. At the time this moraine was formed LeSueur county carried the southern border of the ice-sheet. Past this border the great lake Undine, to be described in chapter XXIII, poured its waters along the valley where now flows the Cannon river to the Mississippi.

6. *Waconia*. This is typical in Carver county. Its chief interest lies in the fact that when the ice which had formed it retreated, the waters to the south-west broke through and found the Mississippi river at Saint Paul. Thus began the glacial river Warren.

7. *Dovre*. The Dovre hills, Kandiyohi county, are typical of this moraine. The ice had retreated across the Minnesota river at this stage.

8. *Fergus Falls*. Through Fergus Falls this moraine stretches northwest and southeast across Otter Tail county.

9. *Leaf Hills*. This forms the great bend of the Leaf hills and causes the most striking topography of western Minnesota. The Fergus Falls moraine merges with it along the highest part of its course in the southerly townships of Otter Tail county.

Beyond the Leaf hills the moraines have been followed but partially, yet Mr. Upham has given these additional names which designate moraines indicating a united northward retreat along the entire northern border of the state.

10. *Itasca*, a broad belt of drift hills extending north and south along the east side of lake Itasca and thence to the south side of Leech lake.

11. *Mesabi*. This moraine stretches across "Beltrami island," that considerable area of high ground within the great northern swamp of the state, between the two lobes of Red lake, past lake Winnibigoshish and along the north -sabi range.

12. *Vermilion.* This is a belt of low rounded hills, made up to a remarkable extent of boulders and large pebbles. It extends from lake of the Woods around the south side of lake Vermilion and along the continental divide to Ontario.

Other Glacial Features. Other names are met with as one reads the literature of glaciers and the glacial epoch. The things themselves are sometimes seen as one surveys the state. Drumlins are more important in Wisconsin than in Minnesota; and in Massachusetts they are counted by thousands. They are often quite high and show how gravity and weathering smoothly round their surfaces. Osars occur, also called Eskers, like those about lake Johanna; Kames are of lesser interest, while Kettle holes are comparatively frequent depressions.

Lakes. A noticeable feature of the state is its thousands of glacial lakes. The waters of some lie in depressions due to the unequal distribution of the material transported by ice-streams, others rest in hollows in the harder rock left where softer rock-masses are worn away by glacial action. Numbers were also formed during the waning days of glacial time that were drained away by the melting of the barriers of northward retreating ice. Many of these extinct lakes have already been counted, and many more will be traced in the future as the surface of the state becomes better known. The story of the lakes will be told in another chapter.

Practical Comments. Directly or indirectly glaciers accumulated nearly every bed of clay and mass of sand in Minnesota, from which material is used in building operations. These deposits are becoming rapidly more important as the forests are cut away, and men find it necessary to build of brick and stone.

For the farmer, the use of the glacier is peculiar. It mingled the material of his soils in a way possible by no other agency. The light soil and the heavy, the rich soil and the poor, were intermingled until a surface was prepared possessing a wider diversity of qualities than could be formed in any other way.

For Further Reading. Pages have been written describing the geographic and geologic features of the state due to the ice invasions discussed in this chapter. The best paragraphs for further illustration are found:

Final report, Geology of Minnesota:

The distribution and characters of the drift, N. H. Winchell, vol. I, p. 116.

The glacial drift of Blue Earth county, Warren Upham, vol. I, p. 439.

Glacial and modified drift, Aitkin county, Warren Upham, vol. IV, p. 69.

Glacial geology of Cass and Hubbard counties, J. E. Todd, vol. IV, p. 85.

CHAPTER X.

WATERS IN THE GROUND.

The Datum plane—Circulation of underground waters—Digging a well—Insanitary conditions—Composition of underground waters.

WE SPEAK OF THE SOLID EARTH, and associate therewith the thought of a perfectly compact body. But no part of the earth yet explored by man is thus compact. In every slab of Saint Cloud granite ten feet square and two and a half feet thick there is not far from one gallon of water; the ancient volcanic rocks around Duluth must contain as much; the dolomites quarried at Frontenac, Kasota, and Mankato carry a larger quantity; the sandstones at the famous quarries along the Saint Croix, Minnesota, and Mississippi rivers can carry as high as a gallon of water to every cubic foot; and the gravel beds in almost every portion of the state may in inverse ratio to their content of clay carry as high as 25 per cent of water. A simple arithmetical calculation of the rocks beneath one's own farm or city home will show a water-storage sufficiently large to maintain a dense population.

The Datum Plane. City engineers speak of the Datum. They mean the plane established in the lowest part of the city or other designated district from which

measurements are made, both of heights and depths, in determining the position of water and drainage pipes in the city. In Minneapolis, for instance, the datum plane is that plane parallel with the surface of the sea, and 709.53 feet above its level, as established by the lake survey of the government. This cuts the water level of the Mississippi river near the Lake Street bridge. Since its establishment, the city has been extended southwards; consequently from that point down the river all positions below the one named are read minus. At Saint Paul, the plane of 694.786 feet above tide, often written A. T., is the city datum; the Union depot in that city is read + 10. At Duluth the level of lake Superior is the datum, 602.2 feet A. T.

The Bench Mark, abbreviated B. M., graven on metal firmly embedded in stone, is located by a government engineer to name the height of the particular spot above the sea. This is useful in determining levels as they are needed in working out the practical problems of drainage and water supply.

The water in the earth's crust has its datum. For coastal lands this is the sea level; for great interior

Fig. 38. Cross section of an island showing capillary attraction raising the water above the level of the sea. It illustrates the standing of water in the glacial drift above the surface of the underlying harder rock.

plains and prairies, the datum is at some point above the sea, and frequently it is hundreds of feet above it. The materials of the earth's crust are the determining factor. If the rocks of a region are compact and do not carry waters readily, the datum line or upper plane of underground waters is quite near the surface. Water

enough for domestic use may be obtained; but when the rocks are porous, like sandstones, or broken and jointed like limestones and dolomites, the water settles down as through a filter and comparatively deep boring is necessary to reach it.

Circulation of Underground Waters. The water which lies in the rocks is always in motion. If it be temporarily in hollows, the circulation is extremely sluggish and the water becomes so loaded with mineral

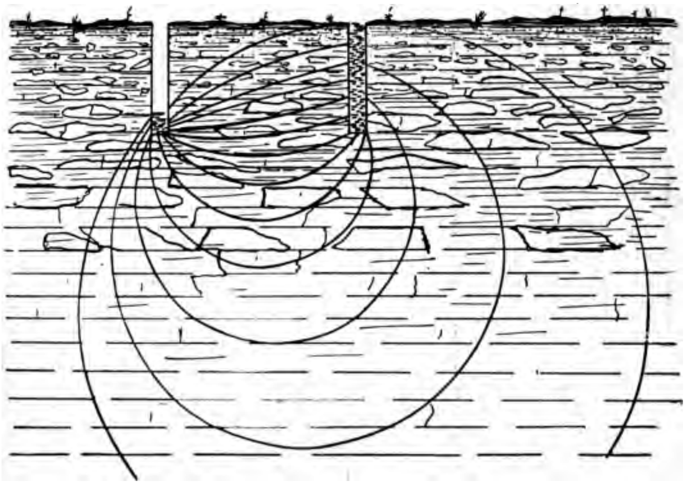

Fig. 39. The movement of underground waters. The well at the right filled with water is drained by another well at the left. The lines show the direction of flow as the water percolates through the rocks. After Van Hise.

substances as to be unfit for use. That movement *does* take place and circulation *is* maintained has been proved in many ways. The movement of underground waters is extremely important, for, by it, nearly all the mineral deposits within the earth's crust have been formed or perfected. Mineral salts are taken up, assorted, re-

compounded, and segregated into numerous or extensive deposits.

Circulation may be vertical or horizontal. It is vertical when the release from pressure, or point of escape, for a given locality is lower than the point at which the water lies; it is horizontal when the point of escape is merely sufficiently low to induce a current toward it from the area of water storage.

Above the datum plane, or ground water plane, circulation is reasonably free and quite directly downward. A small amount of mineral salts is taken up by the water; it contains organic matter and becomes filtered by percolation. In its progress, organic mat-

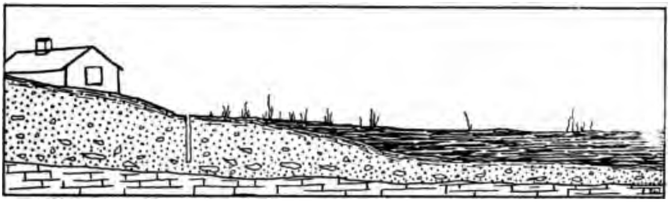

Fig. 40. A shallow well in an insanitary situation. The glacial drift in which it is sunk is so porous that swamp water percolates into it and maintains its supply.

ter is intercepted by grains of sand and crystalline particles. The water is cooled and that mineral habit imparted to it which long usage has taught us best to enjoy. When a layer of clay, shale, or limestone obstructs this downward flow, it forms a bed along whose surface water flows copiously. Cavities and crevices are filled, and every part of the ground becomes saturated.

Digging a Well. A city within a very few years gets beyond the practice of sinking shallow wells for its water supply. The ground becomes so saturated

with impurities of every kind incident to community life that the waters drawn from it are unhealthful. Dead organic matter, always present in natural waters, is dangerous through its decay. Decay brings a dense population of bacteria and infusoria, as well as plants and animals of higher rank. These, taken into the human body, feed upon its tissues until they break them down. Noxious gases are also evolved in the process of decomposition. On the other hand, living plants and animals exert a wholesome effect; the former set free oxygen, which is able to oxidize and thus make inert the gas-generating, poisonous matter. Yet when plants and animals exist in domestic waters to such an extent as to produce serious annoyance, they are unwelcome, and their subsequent death and decomposition is a source of danger.

In rural Minnesota, under sensible precautions,

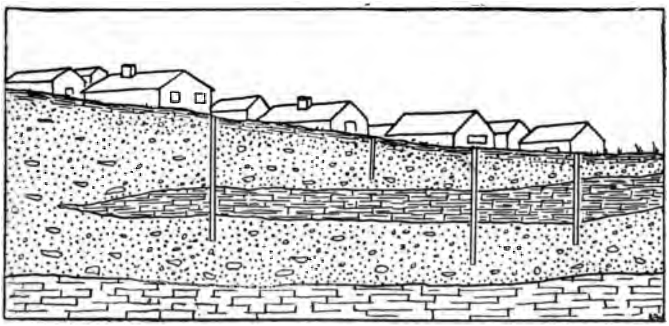

Fig. 41. Another irsanitary situation for shallow wells. In cities and towns "the ground becomes so saturated with impurities of every kind incident to community life that waters drawn from it are unhealthful."

wells give an excellent and rarely failing supply of wholesome water. When a surface well is dug to the depth of 20 to 50 feet, this hole becomes an under-

ground cistern in which collect wandering and percolating waters. If a bed of clay is cut through, and sand or gravel is reached, the prospect is excellent for a wholesome and permanent water supply untainted by organic impurities; the probabilities are that the water has flowed far enough since leaving the surface to lose its impurities, and has flowed over pebbles enough to deposit that extra load of mineral contents taken up in its sluggish hours.

Composition of Underground Waters. Since waters to a certain extent dissolve the minerals with which they come in contact, they are always more or less "mineralized." Hence within the earth they partake of the character of the underlying rocks. If these rocks are sandstones, quartzites, granites, schists, all difficultly soluble, waters percolating through them are not strongly tainted; limestones and dolomites make hard water; shales and clays sometimes produce a saline and bitter water; while rocks carrying iron will produce a chalybeate water.

Most Minnesota wells are sunk in clays, sands and gravels. If this material is made up of granite and sandstone fragments, the water is not very hard; if of limestone, it is hard. When clays and shales occur with sluggish underground circulation, the water is sometimes abominable. In such districts it is difficult to get a wholesome water-supply.

CHAPTER XI.

SPRINGS.

Springs defined—Flow of springs—Location of springs—Streams emanating from springs—Composition of waters—Economics of springs.

SPRINGS ARE NATURAL or artificial. Natural springs are normal flows of water from the earth; artificial springs are shallow wells or artesian wells. Natural springs occur wherever underground waters come to the surface. Water in the ground flows along planes or channels of least resistance. It may first percolate, but sooner or later it wears for itself a well-defined water-course. If sand rests upon a compact rock, the spring, or the outlet of the percolating waters, will be where the lowest point in the contact plane between the two comes to the surface of the ground. This is usually upon a hillside or in a river valley, although it may be upon a level plain or even a hilltop.

Flow of Springs. People sometimes think a great mystery attends the flow of a certain spring, that it could not be where it exists save as a phenomenon. Such a case, when investigated, shows gravity involved in the flow; but gravity may exert its force miles away from the spring. A long underground channel may result from underground seepage; a cap of quite im-

pervious rock may extend long distances; fissuring may connect the spring with distant water accumulation; the faulting of the rocks may open up channels of circulation in unexpected directions. There is in every rock formation such a maze of cracks and cracklets that the discovery of the source of an underground stream may become a hopeless task.

The seeming paradox of spring flow is that water can be obtained from ground above the level of the ground waters from which it is drawn. Rain waters soaking into the ground are dispersed; they flow widely and are but slowly brought to the water level of the region. Capillary action, too, aids in holding the particles of water suspended in the porous rocks. The height to which this accumulatian of water rises varies with the character of the rock material. This retention of rainwater in the ground becomes of no little importance to communities; thereby water can be obtained in hundreds of places where othewise it would be impossible to reach it. It is not only held in the soil, but is brought up through it and utilized by growing plants and animals. Water is thus made to feed many a spring which otherwise would not exist. It is quite probable that every spring in Minnesota is fed from local rains. Soaking into the ground, the waters percolate through the upper rocks, sometimes taking months to work their way through their devious channels. They dissolve minerals and carry along this added load in solution, some much, others little. Indeed, dissolving and transporting rock materials is the special work of underground waters.

Location of Springs. While springs may be said to be common in this state, they are by no means evenly distributed throughout it. There are many large

areas where not a spring is known; others in which they are both numerous and copious. Excepting the slight shrinkage from chemical change and rock absorption, waters that soak into the ground from rains are not lost as a surface agent. They find their way

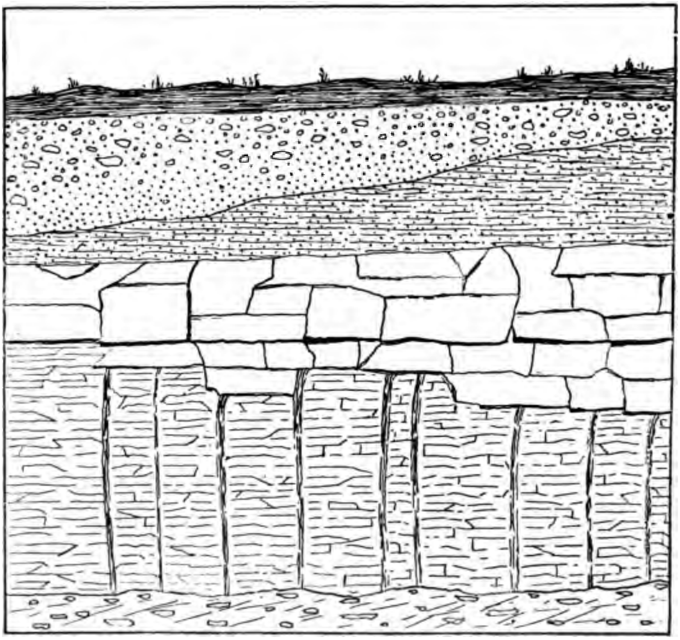

Fig. 42. A group of springs at the Maloney quarry, southeast Minneapolis. Waters sink through the overlying drift to the limestone and make their way through the jointed upper portions until the more impervious layers are reached. In this case quarrying affords opportunity for their escape.

onward through numberless pores, joints, and fissures until they finally reappear.

The bluffs of the Saint Croix, Minnesota, and Mississippi rivers and their many branches afford almost perfect conditions for the occurrence of springs.

The porous and compact rock formations alternating with each other throughout this portion of the state have alike been cut through by these great streams, and along the walls of the resulting gorges are thousands of springs, some great, some small. The water sinks from the surface to a more compact rock-layer, and flowing along this comes to the surface at the edge of the gorge. Shales, dolomites, and shaly sandstones are the compacter rocks in this part of the state.

In northeastern Minnesota, the steep slopes along the shore of Lake Superior yield hundreds of springs of most delicious water. The rocks are of the crystalline types: they are considerably fissured; their surface is quite uneven, as a glance at the elevation map will show, and they are covered with glacial drift. These rocks are also of the most insoluble kinds; as a consequence, the waters are the freest of mineral impurities, and so are the softest, in the state.

Salt springs have long been known in northwestern Minnesota. There are several salt rivers here, streams originating in these springs. These waters have played an important part in the physical history of the Red River valley. They were formerly resorted to by large numbers of game animals, and their vicinage was excellent hunting ground for both Indians and white men.

Another remarkable region for springs is the foothills of the great Coteau in the southwest. Rains fall upon the plateau portion of the Coteau, soak into the earth, and, seeping northeastward, reappear in hundreds of springs along the slope, some five miles wide and descending 50 feet or less to the mile, througout the long distance spanned by Cottonwood, Redwood, Lyon, and Lincoln counties.

A spring sometimes produces a small stream of water. The great majority, however, are indicated by a ranker growth of vegetation, and are discovered only by digging a small hole as a collecting basin for the water. There are, in several localities, exceptionally large springs: at Swedes Forest in the Minnesota valley is a spring having a strong irony taste so large

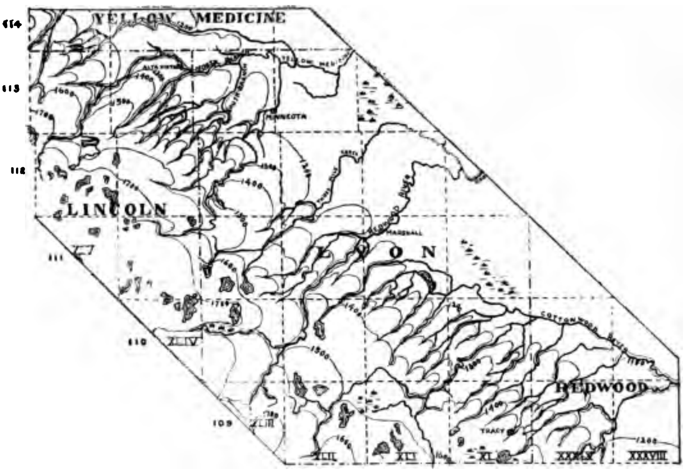

Fig. 43. Map showing situations of springs along the northeast slope of the Coteau des Prairies. The rain water gathered upon the top of the Coteau soaks into the glacial drift and makes its way to the surface along the slope through minute underground channels.

that a stream 3 to 4 feet wide and 8 to 10 inches deep constantly flows from it. Indeed, such springs are not uncommon. Near Otisville are many large springs. In northern Minnesota certain springs are widely known to hunters and explorers; they are, in that sense, well-known resorts. On the international boundary, Minnesota boasts of a spring of ice-cold water fed by

the perpetual ice, which lies in a deep gorge so situated as to be protected from the heat of the sun's rays. On the other hand, no warm or hot springs are known in this state. The temperature of spring water is simply relative. In summer it is cold because its temperature is so much lower than that of the air to which we are adjusted at the time of drinking; in winter it seems warm because of the cold air which environs us.

Composition of Spring Water. While spring waters are admittedly impure from intermingled mineral elements, they are universally regarded as the most wholesome of potable waters. In districts of moderate slopes, spring waters are clear and fairly pure. For this reason they afford a more wholesome supply of water than do lakes and surface streams constantly receiving the wash of fields and meadows. If, as is claimed, one-third of all the diseases which afflict mankind are due to the use of impure water, the subject of springs should be well understood. In the Red River valley and other portions of the state, particularly westward, many epidemics have been traced to the condition of the waters, more particularly those coming from shallow wells. With the reclamation through agriculture this trouble is disappearing and the water supply in rural districts of Minnesota is as good as that of other regions. A knowledge of the character of the underground water supply should not be meagre. The spring waters of Minnesota contain calcium carbonate, common salt, hydrous magnesium sulphate, or epsom salts, and various salts of soda, potash, and iron. Well waters are quite similar in composition.

Mineral Springs. While all waters percolating through the ground carry mineral substances in solution, only those are called mineral that possess some

content in sufficient quantity and quality to impart medicinal properties. A score or more places have springs of recognized mineral quality, the longest known, perhaps, being those at Minnesota City, Owatonna, Minneapolis, and Otisco.

The Economics of Springs. Springs play a most important role in the development of the state. No farmer locates his buildings without reference to the water supply; no village is established where neither creeks nor springs occur. It is important to know whether there is a difference in the hardness or other mineral content of different springs and wells. The general slope of the ground, and especially of the underlying rocks, is an important economic feature of any district. It has been stated that the springs of Minnesota are due to the rainfall. With the average rainfall of the state at 28 inches, on every 80 acre farm there falls each year 8,131,200 cubic feet of rainwater. If one-third of this soaks into the ground, there must be 2,500,000 cubic feet available for springwater somewhere. This is enough to supply over 17,000 horses with 30 quarts each of water daily throughout the year

CHAPTER XII.

ARTESIAN WELLS.

Definition—Necessary conditions—An illustration—Distribution of wells—Porous rock strata—Still other porous strata—The Red River valley—Figure 47—Saint Paul water supply.

An artesian well is a hole bored through impervious rock strata into a water-charged, impervious stratum, out of which water will flow as forced by hydrostatic pressure.

Artesian wells are resorted to when surface supply is insufficient to meet ordinary demands or when this supply is not of a satisfactory character.

Sometimes water thus liberated rises hundreds of feet, and sometimes it stands so low in its channel that only pumping will bring it to the surface. The hole bored into the ground is an artificial fissure; the artesian well is an artificial spring.

Necessary Conditions. With these definitions in mind, we may state the essential conditions, physical and geological, upon which successful artesian well boring depends:

First; there must be a porous stratum of rock lying between two impervious strata.

Second; there must exist an area where this porous

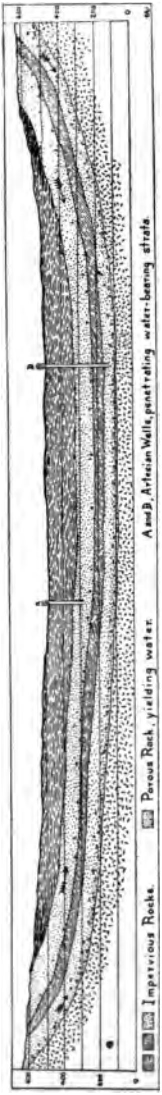

Fig. 44. Cross-section illustrating the position of water-bearing rock-layers.

stratum is exposed to saturation from rainfall. This area may be near at hand, or it may lie hundreds of miles away.

Third; there must be a sufficient fall from this exposed area to the region of the well—which region is called the Artesian Basin—to insure a steady and abundant flow of water.

Fourth; there must be sufficient freedom from fissures and dikes to insure a steady flow, without great loss, from the rainfall district to the artesian basin.

Fifth; there must be an adequate rainfall in the area of exposure to furnish the necessary water.

An Illustration. Having read the conditions, each one of which is absolutely essential to the successful working of an artesian well, let the reader scan figure 44. The kinds of rock are shown by different markings, the usual "conventions" of geologists and civil engineers, which are explained at the bottom of the figure. Two sandstone beds are shown. Above and below is an impervious rock, necessary below to prevent escape of the water downwards, and above to secure that pressure requisite for forcing water to a height above its ordinary level. The water bearing sandstones extend both right

and left to the surface, where they are considerably higher than at the two wells, A and B. Water flowing down from the exposed surface and unable to escape is under enormous pressure in the lowest portions of these beds. This is manifest the moment a hole is made through the compact, covering rock, as by the boring of a well. If the beds all incline gently in one direction until they become deeply buried beneath overlying rocks as is the case in the middle Mississippi valley the result is the same. If the well be located upon higher ground than the exposed surface of the water bearing sandstone, there can be no natural flow; the water is then raised by a pump. Such raising of the water is necessary in many localities. If the supply needed be small, a windmill is often used.

Distribution of Wells. The distribution of artesian wells depends entirely upon the character and attitude of the underlying rocks. These must be sufficiently porous to allow free percolation. Where this is not the case, the little reservoir formed by the bore hole will not fill with sufficient rapidity to produce a flow. Crystalline rocks, and these include ancient and modern volcanics, granites, gneisses, schists and many shales, will not yield artesian wells. Neither will beds of limestone or dolomite, or quartzite. A little knowledge touching the distribution of rocks in Minnesota will show one where these artificial springs may be successful. In the northeastern part of the state, from the International boundry southward beyond Stearns and Sherburne counties, the rocks are so crystalline, and usually so thinly covered with later deposits, that there is but little hope of successful artesian wells. In the Red River valley, on the other hand, there are porous rocks in such position that artesian wells are

successful. This is the case at many points from Kittson county southward to the Iowa line. Locally, throughout the Coteau region in the extreme southwestern corner of the state, artesian wells are often successful. Many wells have been bored in the southernmost two tiers of counties; a narrow belt of artesian wells has been developed from Hinckley southward to the Mississippi river. In all these localities there lie beneath the surface beds of porous rock, either gravel, sand, or sandstone, over which is a compacter layer. These may belong to any age of geologic history from the Cambrian to the Glacial. Below the Cambrian the rocks are too much altered, that is, they are too crystalline, to permit the free circulation of water; artesian wells in them are extremely rare.

Porous Rock Strata. In southeastern Minnesota, upon the ancient crystalline rocks which are everywhere impervious and never water-bearing, there lie several formations of sandstone so porous that they are capable of carrying enormous quantities of water. These sandstones have various names in their different parts and even the same formation has different names at different localities, as Hinckley sandstone, Saint Croix sandstone and so on. These water-bearing sandstones extend underneath the entire southeastern part of the state and

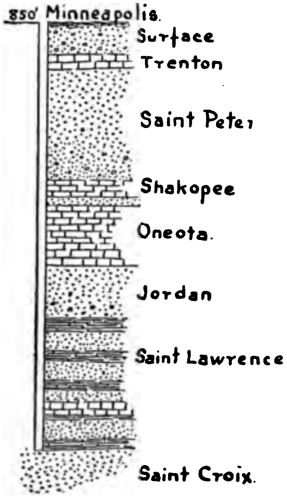

Fig. 45. Section of the West Hotel well, Minneapolis.

underlie adjacent Iowa, Wisconsin and Illinois as well.

The lowest of these sandstones occurs in the west end of Duluth, stretches in a narrow belt southwest past Sandstone and Hinckley and spreadsout into a bed reaching from Cottonwood County to the Mississippi river. Above this bottom layer are several other sandstone formations separated from each other by formations of dolomite and shale, both quite impervious rocks. They are known by various names, the more common being Potsdam sandstone—called also Hinckley, Saint Croix and Dresbach—Jordan, New Richmond and lastly the Saint Peter, that beautiful white sandstone at Saint Paul and Minneapolis over 160 feet in thickness.

In this series of sandstones, possessing a total thickness of hundreds of feet and so porous that each cubic yard contains gallons of excellent water, there lies a reservoir of inexhaustible water supply. The question is, how can it be obtained? Not every city or community is successful in its attempts to secure it. Sometimes one or more of those necessary conditions is lacking; if so failure must be looked for. Again, there may be some local condition of the rock which prevents a sufficiently free percolation. As a rule study of the local situation will determine within a narrow margin of guess whether in any locality, an effort to obtain artesian water will prove fruitful or fruitless.

Still other Porous Strata. In the western part of the state the porous rock formations above named do not appear but other water-bearing rocks occur. A number of towns south of the Leaf hills have secured an excellent supply from sandstones that are regarded as Cretaceous in age and doubtless of the same Dakota sandstone bed which has made the artesian

basin of North and South Dakota known throughout

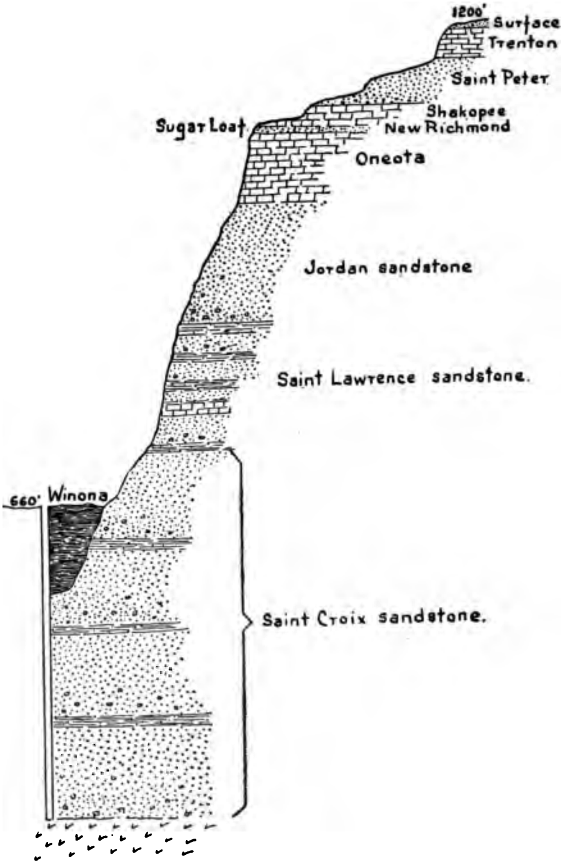

Fig. 46. Section of artesian well at Winona. The portion of the figure above Sugar Loaf is shortened from the distance to Utica that the rock series might be compared with that at Minneapolis, seen in figure 45.

the world as one of the most magnificent of all underground reservoirs for water supply.

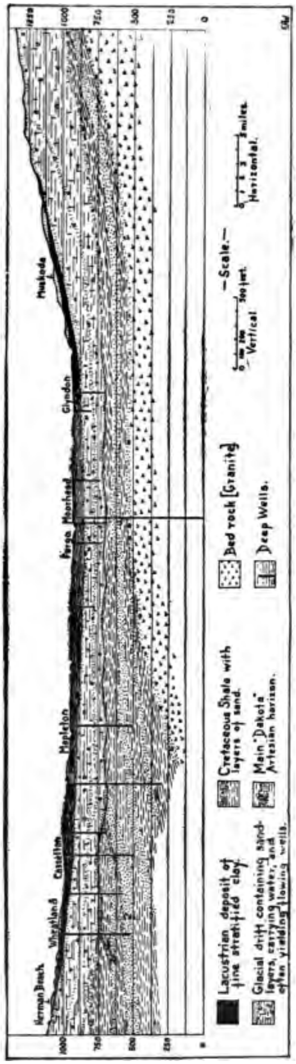

Fig. 47. Section across the Red River valley through Moorhead.

The Red River Valley. On the broad fertile plain we associate with the name Red River valley many artesian wells have been obtained. The rocks which yield the water are vastly younger than those in the Mississippi river valley just discussed; they also belong to more than one period of geologic history.

The depth to which they are sunk varies with certain local conditions. The shallow wells of the region vary between 10 and 50 feet; those called artesian between 75 and 500 feet according to the location and its relation to the underground distribution of the water-bearing sandstone beds. While water can generally be obtained there are curious cases of failure. Such are doubtless owing to unexpected changes in the direction towards which the percolating waters flow or to some exceptional compacting of the water-bearing rock.

Figure 47 was drawn from a sketch prepared by Professor Charles M. Hall, of Fargo, expressly for this work. It presents in clear relation the several physical features of the Red River valley. The entire breadth of the valley itself is the first seen; the several beaches accumulated by the glacial lake Agassiz, which extended across the valley from Muskoda to a point beyond Wheatland, shown by the dotted dome-like elevations along either slope of the valley; the black carbonaceous lake clay which stretches across the valley from beach line to beach line, from a few inches to 100 feet thick and extending from Breckenridge to Winnipeg and beyond; and lastly the succession of rocks of the various types present in the valley down to the early granite which has been reached at several places notably at Moorhead where it was penetrated several hundred feet.

Saint Paul Water Supply. That artesian wells grow in importance as a source of water supply is seen as the various communities of southeastern Minnesota are passed in review. Saint Paul is a notable example. This city draws its water supply from the townships lying north and comprising over 3,000 square miles. There are a dozen beautiful post-glacial lakes in this district whose surplus waters are saved, kept clean, and brought into the city. To their supply is added the product of a system of artesian wells, already thirty or more in number. These wells are in two groups: A shallow one varying between 51 feet and 66 feet in depth, reaching a water-bearing stratum in the glacial drift; the other bored 300 feet and more, tapping Cambrian sandstones and allowing their water to escape upwards. These waters, emptied into the series of lakes just named, there to mingle with surface waters, become a most wholesome supply. The city claims practical exemption from many of the diseases suffered by other communities and incident to a supply of unwholesome drinking water.

CHAPTER XIII.

THE ELEMENTS OF EROSION.

What erosion is—Weathering—Corrasion—Solution—Transportation—Transporting power of water.

Erosion is the wearing away of rocks. It is a complex process. In the first place, the air, the sunshine, the change from heat to cold and back again, the effects of frost, the action of various solvents, all conspire to soften and loosen the surface of rock masses. The extent to which this softening and loosening proceeds depends as much upon the kind of rock as upon its exposure to the action of the agents named. A rock made of quartz grains thoroughly cemented—we call it technically a quartzite—or a massive granite, is slow to receive impression. The non-indurated sandstone or a limestone receives impressions rapidly and yields to subaerial agents with comparative readiness.

Weathering. Weathering includes all those agencies which disintegrate and disrupt exposed rocks. Gravity too becomes a most important factor in the work. They may be briefly enumerated: 1. *Rainwater* driven against the rock surfaces acts as a solvent, dissolves some mineral contents, softens the surface, and washes away loosened particles. 2. *Frost* contracts the rock

constituents, expands the mechanically contained water, widens the cracks and joints, and pries off many fragments. 3. *Ordinary temperature changes* operating in a

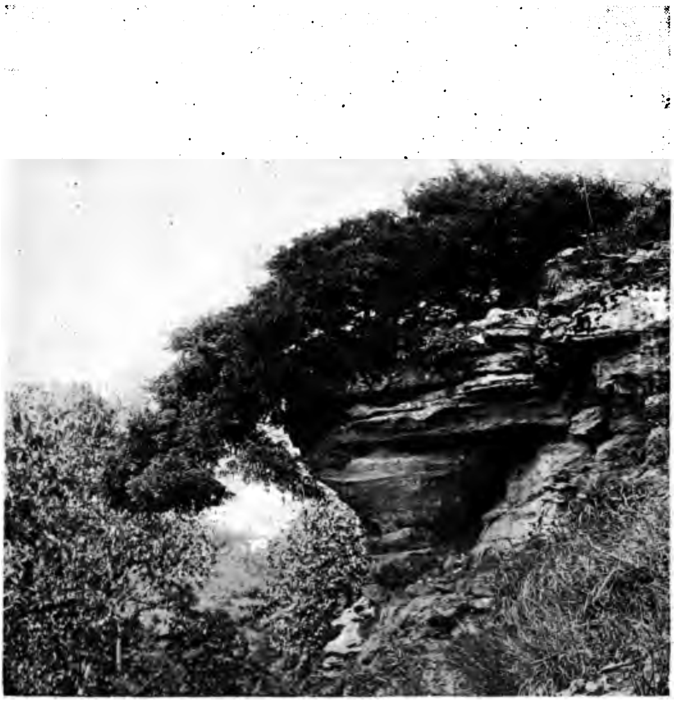

Fig. 48. A juniper bush probably 75 years old has preserved a block of lime stone from weathering until frost and wind have almost completely cut it off. In the Winnebago valley.
Photograph by C. J. Hibbard.

quieter and more constant way, produce a concentric wasting of the rock material, sometimes quite perceptible. 4. *Wind* acts both as a disintegrating and as

a transporting agent and has been one of the most important among all concerned in castellating the bluffs along the Mississippi into their striking and beautiful forms. 5. *Carbonic acid, oxygen, and other solvents* attack the rocks and convert them into more destructible compounds. 6. *Plants and animals* are directly and indirectly members of this group of destroying agents. The roots of trees grow into the crevices of rocks and exert tremendous pressure in forcing the blocks apart; lichens, mosses, and fungi feed upon the moisture drawn from rocks, and, as poultices, hold moisture and make soft the rock surfaces to which they are attached. Their decay affords acids, called by chemists, humic acids, which have great solvent effect. Animals, too, particularly gophers, moles and earthworms, continually loosen the soil and by their burrowing admit air and water to act freely upon minerals that otherwise would not be exposed to so vigorous action.

The united effect of these agencies brings great results in the course of time. It is largely through weathering that the bluffs of the Mississippi river stand several miles farther apart at La Crescent than at Hastings. In every part of the state the rocks show the result of the constant attacks of these agents of the atmosphere.

Corrasion. The complex action of the combined agents just enumerated upon rock surfaces prepares them for the next process, that of corrasion, or the scraping away of material. Corrasion is essentially a physical process. It is accomplished by the wearing action of streams when the water carries hard fragments, fine or coarse, and beats these fragments against the surfaces over which they are flowing. When of considerable size, they exert a remarkable power in

cutting away surfaces of rocks, and the more perfectly weathering agencies have loosened the material, or, by

Fig. 49. The face of Sugar Loaf, Winona. Weathering acting upon a rock of varying hardness makes the surface in time extremely uneven.
Photograph by H. F. Nachtrieb.

chemical reaction, converted it into softer mineral substances, the more thoroughly is the work of corrasion

accomplished. We can hardly think of corrasion without transportation, because, unless each particle were displaced, the next particle could not be reached. But weathering prepares the rock for both processes, corrasion and transportation. The final goal of all material transported by running water is the sea.

Fig. 50. A lake Superior lava flow cut by the waves. Varying hardness of the rock yields this result.

Solution. Water is the universal solvent of nature. Everything yields to its chemical power. The hardest and most durable rocks, like gneisses, granites, and diabases, while disappearing beneath the influence of chemical affinity, are much more slowly corraded than are the softer and less indurated kinds, such as dolomites, shales and sandstones. By dissolving rocks, the waters take up the several minerals and carry them along for an indefinite period, and for world-wide distances. A mineral is dissolved in water when it is so minutely subdivided and its particles so intimately and completely dispersed through it that they not only become invisible, but cannot be separated by

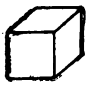

Fig 51. A unit block of transport.

filtering. The water with this added content is almost as mobile as without it. The Mississippi river, as it flows past Winona soon to be beyond the boundary of the state, carries per gallon 16 grains of minerals in solution. In every one-million gallons of water there are 3550 pounds, or over 1¾ tons of rock material leaving that part of Minnesota drained by the Mississippi river. Add to this figure the amount estimated as carried by all other streams and there must be not less than millions of tons yearly deposited in the sea. Corrasion, then, is a most important ally in the destructive work rivers are continuously carrying on.

Transportation. Water transportation is the moving of the loosened rock material towards a place of rest. The entire surface of Minnesota is being eroded and transported to the sea. In places the process is extremely slow, and throughout many miles no doubt the process is one of accumulation rather than of removal. Where lakes are filling and swamps are accumulating debris, we fail to see the degradation of the land. But the water of any stream, if analyzed, shows a content, very perceptible to the chemist, of mineral matter. This is the land being removed beyond the confines of the state. It is interesting to note what a powerful natural transportation line a river is. Experiments have been made which show the following results:

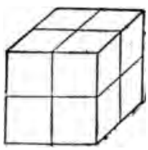

Fig. 52. A block having four times the obstructing area and eight times the bulk of the unit, figure 51.

A velocity of 3 inches per second will carry fine clay and silt.
" " " 6 " " " " " " sand.
" " " 1 foot " " " " " pebbles ½-in. in diameter.
" " " 2 feet " " " " pebbles 1-in. in diam.
" " " 4 " " " " " " 4-in. "
" " " 6 " " " " " " 9-in. "

Transporting Power. One significant fact to be kept in mind in reading the foregoing table is that the transporting power of running water increases much more rapidly than its increase of velocity; i. e., if the velocity be doubled, the transporting power of the current is increased sixty-four times. Three feet per second means about two miles per hour. If the working power at four miles per hour be sixty-four times that at two miles per hour, we can, in part, understand the irresistible power of water at the flood stage.

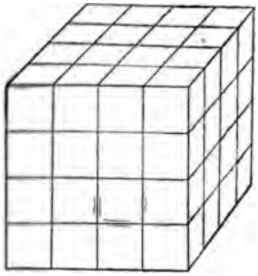

Fig. 53. A block presenting sixteen times the area of resistance and sixty-four times the bulk of the unit block. A current twice as fast will move it.

CHAPTER XIV.

AN ILLUSTRATIVE AREA.

An assumed situation—The beginning of a valley—New forces—Growing complexities—Base-leveling—An illustration.

Let us suppose for the moment Minnesota entirely detached from all surrounding territory, perfectly smooth, with every point at an equal distance from the center of the earth; further, that the state be raised some hundreds of feet above the general level of the states around it. In such a situation, with the rocks perfectly uniform in hardness and chemical composition, there would no inequality of erosion; transportation would be equal in all directions. The outer edges of thc state would be worn off gradually and evenly, like the brink of the waterfall. All the agencies of degradation—sunshine, frost, wind, snow and rain—would result, through their operation, in a uniform slope from the center outward in all directions to the very edge of the state.

The Beginning of a Valley. Did such a supposition conform to the facts, the statement of the problem would be its solution. Nowhere in the world is there such a land mass as has been supposed. No region has equal and uniform slopes, nor is the rock mater-

ial of the same degree of hardness and chemical composition over any considerable area. The rainfall is not the same at different points; the effect of the sun's rays is always different at different localities. Taking, therefore, these conditions, valleys would be formed if the area of the state were raised to a point where erosion and transportation are effective. The problem involves the retreat of the valley sides from the stream center, as well as the retreat of the edges of the assumed erosion block, the state. The cutting down of the valleys is equivalent to carrying the edges of the block in from the extreme outer border towards the center of the land mass. Erosion is vastly increased by the increase of the valleywall surfaces exposed to its action.

The proportion of rain-water devoted to stream formation, called sometimes the "run-off," is gathered in any slight depressions and channels that may occur on the surface due to glacial adjustment, or the dissolving of more easily soluble minerals by the saturating waters. Rills are thus produced which, with increased volume, produce increased flow, and, with increased flow, more and more rapid erosion. Along the lines of the greatest erosion the rivers are laid off, and, with new forces brought into play, there is a continual increase in the results attained.

New Forces. If the rocks were soft, erosion would be rapid; if hard, correspondingly slower until the rate of corrasion and removal would be so gradual that a generation could see scarcely a perceptible trace of its results. The valleys would thus be extended until the great waterways of the state all had their source in its central part. Minor streams would exist all around the borders, flowing not into master streams but di-

rectly off the sides into the lower lying adjacent states.

But variations in rocks *must* be reckoned as a factor, for rocks are never uniform in their physical characters over extended areas. The tortuous windings of ravines and valleys are due to jointing, varying hardness, different degrees of porosity and inequalities of slope as the chief factors of variation during the time while the valley is developing.

Growing Complexities. The interplay of forces brings about notable results. Streams unite with one another until a drainage system develops. A drainage basin thus becomes a sharply defined geographic factor. This is accomplished through the universal process of cutting off the weak and augmenting the strong. Lateral streams play a constantly more important part as compared with the original stream, because greater altitude and more rapid slope conspire to their advantage. This advantage is improved even to many known cases of the rankest piracy. Not many such are in Minnesota because the streams of the state are too young to harbor such older criminals as pirate rivers must be.

Baseleveling. The final work in the result of erosion which we picture upon a level tract is to make the tract again nearly level. Of course water will not make an absolute plain by erosion; it requires a slope for transportation. When the process of denudation reaches a point at which accumulation equals removal, no further evolution of land forms is possible. This is called the baselevel. Baselevels of large extent are extremely rare, but there are many places where erosion has well nigh reached this baselevel stage. This is called the peneplain stage, that is, almost a plain. New England, according to geographers, is for much

of its surface in the stage of peneplanation, and Minnesota has attained to several such stages in the course of her physical history. From such a degree of erosion, or, in other words, between such an extreme old age of a land form and the extremely new age of nearly the entire area of the present time there are innumerable gradations.

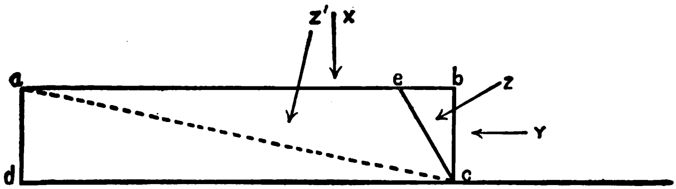

Fig. 54. Assumed erosion block, simplest type.

Figure 54. Let us assume the state of Minnesota as a block of ordinary earth-material elevated to a height above its surroundings. Let figure 54 *a b c d* be a cross section of this block from center *a* to edge *b*. The atmosphere and occasional rains act upon it, in short, all the forces considered under weathering. Weathering alone simply disintegrates and re-adjusts rock material. But rains fall: the flow of water introduces another factor into the example. The accumulated water moving off edges carries along and downwards over the vertical sides the disintegrated material. Assume the rain falls equally over the entire surface; all which falls must pass *c* whether it falls more copiously towards *a* or towards *b*. The rate of flow decreases rapidly in passing from *c* to *b* or along any inclined surface between *c* and *a* as *e c*. It is to be noted that the particles of earth at the point *b* are acted upon from two directions instead of from one as is the case at points not at the exposed edge. It is in corresponding degree more greatly affected by the agents operating. The edge *b* moves back towards *a* and, through a series of stages, the constant forces *y* and *x*, become represented by the variable force *z* which finally becomes *z'*.

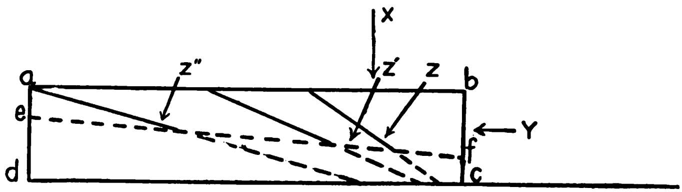

Fig. 55. Erosion block modified. Type still simple.

Figure 55. Given uniform material, steep slopes become steeper and rapid streams become more rapid, yet conditions surely intervene to modify the slope

of the surface or slacken the speed of the current. Instead of steadily and evenly corrading the edges of the erosion block *a b c d* and pushing back its boundary through the lines *z* and *z′* to *z″*, the obstruction of the channel interferes with the cutting away of the block until through a long succession of conditions the surface becomes the complex line *a f.* It will be seen, as further figures are studied that this is not the ultimate stage in the process of land degradation. It fs rather the stage shown by streams in middle life like those in southeastern Minnesota, where there is no exceptional condition to interrupt the steady progress of the work of erosion.

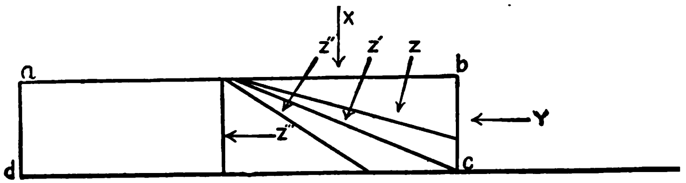

Fig. 56. Erosion block modified by hard upper layer.

Figure 56. This figure assumes the introduction of an obstruction so difficult of removal that erosion proceeds with extreme slowness. The removal of the surface is retarded almost to cessation. The action in the direction *x* is reduced to a minimum; that in the direction *y* steadily proceeds. The result, if unhindered by accumulating debris, would be as seen in the relative positions of the lines *z*, *z′ z″* and *z‴*. Certain sorts of volcanic intrusions, dikes for example, tend to produce this form of land surface: the best illustration the state affords is the Pigeon river. At Pigeon falls a dike of volcanic rock over one hundred feet in width cuts across the course of the river and produces the beautiful cataract figured in a subsequent chapter.

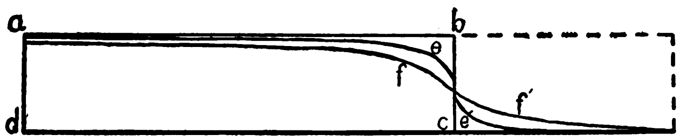

Fig. 57. The course of erosion developed.

Figure 57. In the preceding cases weathering and corrasion have been considered without taking into account the disposal of waste. This cannot be ignored. Taking note now of gravity as acting with weathering upon the erosion block, the surface soon becomes curved, as at *e*. This form is seen in typical profile along the Mississippi river bluffs from Red Wing to Jefferson. As streams gather they distribute the material outward from the foot of the vertical *b c* along the course *e′*, the finer material being carried furthest and spread out in a thin sheet, the alluvial plain. The continued working of the forces engaged brings the surface of the block up from *e′* to *f′*, distributing the finer debris for many miles.

Thus combining the removal of weathered and worn material and the disposition made of it, the convex curve of erosion and the concave curve of deposi-

tion unite to form the long compound curve of land degradation. The earlier stages of compound curve forming are seen in Minnesota where the wearing of the land has been under exceptionally favorable conditions, due to rainfall, easily comminuted rock formations and a sufficient altitude above the sea to insure the vigorous action of the agents participating.

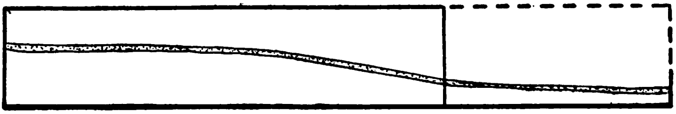

Fig. 58. The base-level nearly attained.

Figure 58. The baselevel is the ultimate result attained by the combined physiographic processes. But little further erosion is possible. The streams have removed practically all they are capable of carrying. As the convex curve of erosion, *e* and concave curve of deposition *e'* become the compound curve *ff'* in figure 57 by steadily, or interruptedly, for oscillations of level may occur, cutting down the surface and carrying the crest of the curve backward toward the center of the block. This retreat lengthens the curve of deposition which is also lengthened by the continuous pushing out of the finer debris. At last weathering proceeds faster than removal; a thick covering of soil and subsoil results. Through the double process the concave curve becomes physiographically the more important. It also develops into the fertile plain, that over which transportation routes are laid and upon which cities rise.

The foregoing figures are inserted as a suggestion merely in the illustration of a somewhat difficult subject. A more extended study of the problem by H. Foster Bain is to be found in the report on the Iowa Geological Survey, Vol. VI, 1897, p. 449-458.

A Conclusion. There are only two ways in which we can conceive of a level tract being formed from an uneven and higher one, or, indeed, a higher one that is even. These are: First, by subaerial agencies, that is, agencies in operation in the open air and upon the land; second, by wave action taking place along a shore line of the sea. Since instances of subaerial erosion are so many and so conspicuous in every portion of the state, and wave action is so extremely rare a phenomenon, the judgment with reference to Minnesota is that subaerial agencies are paramount in moulding the contour features of its area. In these grand operations of valley cutting and plain making, rivers are agents of supreme importance.

CHAPTER XV.

RILLS, BROOKS, RIVULETS AND RIVERS.

Rills—Brooks—The name rivulet—Creeks—Rivers—Further definitions—A gully —A coulee—A gorge—Dalles—A ravine—A valley.

Rills, brooks, rivulets and rivers are streams with varying volume of running water. The work of their water is Erosion and Transportation. This work begins with the raindrop. Wherever the raindrop strikes the ground is the initial of the stream. Gravity universally causes water to seek a lower level. Drops run together, and as they trickle down, rills are formed. Erosion has been accomplished, and transportation is being effected.

Rills are small streams seen wherever waters segregate. They flow not only from raindrops where these are forming tiny streams, but they carry away the water of thousands of springs. They exist wherever the volume of water exceeds natural seepage and evaporation, two processes which dispose of so much water everywhere. Rills occur by the thousand when snows are melting, and by tens of thousands when rains fall. They carry superfluous waters into swamps, sloughs, and larger streams throughout the state. From whatever source these streams converge, from

whatever direction they come, they flow together producing larger streams or lakes, and, as rills, disappear. Through their existence rills perform their work in their own small way, and so are always objects of local interest and usefulness.

Brooks are streams of water, also small, yet larger

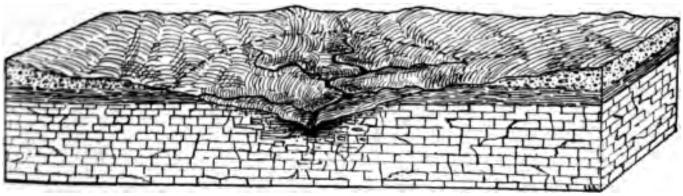

Fig. 59. Springs developing rills. An area with impervious rocks beneath glacial drift is assumed. The spring line is thus determined. With concentration of corroding and corrading capacity the central stream cuts still deeper the underlying rock.

than rills. Theoretically they are smaller than creeks. The name, however, is of somewhat local usage. It is to be noted that the name brook is of most frequent use in those portions of Minnesota that have been traversed by lumbermen from New England, that portion of the country where almost every stream smaller than the Connecticut and Penobscot rivers is called a brook. So it would seem that the term has reference as well to the habit of the people who have entered the state as to any particular size or physical feature of the stream itself.

Rivulet is the name given by many geographers to all streams smaller than rivers. The dictionary makers would have rivulets about the size of brooks. Inasmuch as we never hear "Spunk rivulet" used in Stearns county nor "Hillman rivulet" in Morrison county, we may conclude that for Minnesota "brook" is

sufficient for common needs, and at least sufficiently euphonious for common use.

Fig. 60. A brook meandering through a meadow. The current is so slow that but little downward cutting has been accomplished.
Courtesy of the State Botanist.

Creeks are streams of less volume than rivers. Under this definition any stream not large enough to be called a river may be named a creek, and, indeed, such is the common practice in the state. There is no well-defined distinction between brooks and creeks, nor creeks and rivers. Hawk creek carries considerably more water than Yellowbank river; and Otter creek, had it been named by some other man, might be called to-day Otter river. The scores of streams flowing into lake Superior along its north shore from Duluth to Pigeon river are called rivers with little regard to the volume of water discharged. This is because the Chippewa name for them all was *sibi* (pronouncee see-be), and *sibi* without regard to size of stream is translated *river*.

Rivers are large streams of running water. The Mississippi, although having its source and its smallest current in the state, carries so much water that before it leaves the borders it becomes a very large river.

Fig. 61. A ravine in south Saint Paul. A small stream carries the drainage of a small area from prairie to river bottom.
Photograph C. P. Berkey.

The function of a river is three-fold. It removes from the land by carrying them to the sea such waters as are not evaporated nor soaked into the ground. It cuts down, or corrades, the rocks, both soft and hard, over which it flows; this is erosion. Again, it removes finely divided and worn-out rock material from the land and lays it upon the sea-bottom; this is transportation.

It would be interesting to study how streams have worked in the past. They have existed from the

earliest times when land stood above the water. We cannot doubt that rivers have flowed for many geological epochs over the area now comprised in Minnesota. While thousands of feet of sediments have been taken away, the streams have probably undergone only normal vicissitudes. They have corraded their banks and floors, exposed rock surfaces to the

Fig. 62. The Mississippi river in its new valley stage. The bridge represents the close of an early terrace stage, the top of the limestone beds. *Courtesy of the State Botanist.*

influences of weathering and carried to places of deposition the loads of silt imposed upon them. They have meandered through broadened valleys and performed acts of piracy upon each other until the boundaries of river basins have been completely changed and migration routes for plants and animals have been

laid again and again. The inequalities of the floor on which the glacial drift lies shows this; but the distribution of the drift hides the extent of the piracy and obscures the baselevels of earlier time.

Further Definitions. Water as it runs along does work. As we have considered our area we have talked about the several grooves the streams make. They are all of the same kind, made by the same agent, cut into the same material, and worn by the same tools. To have the difference clearly before us, let us define:

A Gully is a narrow channel freshly cut through rock by running water. The rock may be hard or soft. If the latter, the gully enlarges rapidly, and the "gullyhood" stage of the stream extends throngh a comparatively short period of time. It thus enters its "ravinehood", where other factors are involved in modeling the form and structural features of the channel.

A Coulee, becoming Cooley, is a channel worn by water when excess of rain flows off the land. It is above the spring line and is dry except in wet weather. The word may be applied to the longer stretch of ravine and valley below the spring line and, as localities are named and events transpire, become historic as has the name Birch Cooley.

A Gorge is strictly a narrow passage between hills or mountains. The name comes from the shape of the outlet. It is applied to any narrow, deep valley having precipitous sides, like the Mississippi gorge from Saint Anthony falls to Fort Snelling. It is even applied to other stretches of that and other streams.

Dalles are rapids when a river flows with swift, turturbulent current over rocks. The word dates back to the days of the Hudson Bay company in the state.

In the dalles of the Saint Louis and Saint Croix rivers the "broad, flat rock surfaces" of the dictionary makers are wanting.

A Ravine is a deep channel worn by the stream out of the rock in which lies its course. The word refers to the tearing away of rocks by a torrent of water. A ravine is old enough ordinarily to have upon its walls vegetation representing years of growth. Minnehaha creek from the falls to the Mississippi river flows

Fig. 63. Looking down a valley. One of the many valleys of southeastern Minnesota opening into the gorge of the Mississippi. Lake Pepin is in the distance. A typical valley in its vigorous stage.
Photograph by H. F. Nachtrieb.

through a beautiful ravine. From Minneopa falls towards the Minnesota river is a ravine. These examples, however, are of a very mature type. As time goes on, streams unite, the work becomes larger and the period of "valleyhood" is entered. This is the normal stage of young creeks and rivers. With sufficient flow rather than with length of time, valleys become gorges or canyons; with length of time, coupled with flow and subaerial degradation, gorges, canyons and valleys

broaden into magnificent stretches of the richest land in the world and become the homes of dense human populations.

Valley is a generic word. It means a hollow or surface depression between hills or mountains; and in Minnesota a valley cannot exist without water for a part of the year at least. And size is associated with a valley although here nearly all valleys are young. A valley is a depression with bottom of gentle slope compared with its sides; yet in youth this condition is not attained.

The initial state of a valley, that of its youth, is a period of narrow channel, steep sides and rapid evolution. This gives place to the stage during which the

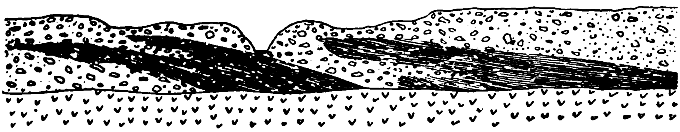

Fig. 64. Generalized profile of a stream cutting its valley in glacial drift. The "V-stage" of valley formation.

banks are pushed further apart, the stream swings back and forth across the silt which it fails to carry forward, as fast as ground, for deposition at its mouth. It is now that meanders are formed; as down-cutting is still in progress terraces result. These structures may have

Fig. 65. Generalized profile of stream cutting. Work advanced from stage in preceding figure to the terrace stage.

a heavy covering of silt or a very thin one. They are so numerous in the state that it is unnecessary to name

a single locality. In time the mud deposit thickens and even covers terraces formed in earlier years, not the earliest, of the valley's history. This is the flood-plain stage. It marks that condition of maturity when the river is an independent factor in earth economy,

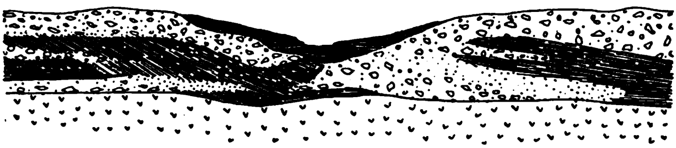

Fig. 66. Work of the stream still further advanced than in the preceding figure. The flood-plain is being formed.

removing here, depositing there and ejecting whatever it may until, through its own work within its own domain it obstructs its own activities and slowly declines into the period of old age.

CHAPTER XVI.

A RIVER VALLEY.

The power in a stream—The source of this power—The divides—The beginning of the valley—The maturing of the valley—Tributary streams—Some conditions of flow—Other Minnesota streams: the Nemadji; the Blue Earth.

WHEN WE GAZE upon a river valley, we admire the beauty or the grandeur of the scene without once thinking of the tireless energy of the flowing water or the millions of units of actual work in cutting down the land the stream is daily accomplishing. Looking at the Mississippi river pouring its waters over the falls of Saint Anthony, the beholder does not think that the power there shown is equal to that of all the engines and machines and pumps of that Queen of Battleships, the Oregon. The strength of 30,000 horses, never for a moment slackening its power night or day, is a good deal. Such are the falls of Saint Anthony.

The Source of this Power. Taking a map of Minnesota and glancing at the falls of Saint Anthony, let the eye follow upward along the course of the Mississippi. A channel always meandering, and in stretches quite tortuous, extends to lake Itasca. It is not deep, yet its banks are high enough to hold all the waters

Fig. 67. A profile from the sources of the Red river of the North to lake Itasca. Distance 15 miles. Vertical scale same as horizontal.

that it gathers. Nowhere has the stream cut into the underlying rocks to an appreciable extent; instead it has cut into, and occasionally entirely through, their covering of glacial drift. The descent of the stream is very uniform from 1462 feet, the level of lake Itasca, down to 802 feet, the brink of Saint Anthony falls. This is a descent of less than 15 inches per mile, for it is more than 500 miles before the falls are reached.

The Beginning of the Valley. Throughout this basin, the Mississippi river and its thousands of tributaries are gathering up such material as they can and carrying it towards the sea. Corrasion, corrosion, and transport extend to the outermost confines; their effects are intensified in varying degree. The valley is so young that these processes go forward at nearly equal pace in every part. The tendency is to concentrate them into somewhat definite lines. Since all the streams are consequent ones, that is, those whose courses are determined by the irregularities of the surface on which they began to flow, this concentration is effected in two ways: first, the water gathers on the lowest portions of the land; then, in flowing further toward the sea, the surface where it flows is worn away and gullies are started.

The material upon which this work is done is the glacial drift and incidentally some wind-blown sand. Yet this material varies in hardness; it is eroded along certain lines more easily than elsewhere. This leads to greater erosion of the softer material. By the combination of rate of flow and quality of material

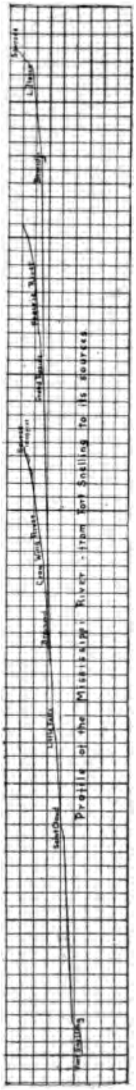

Fig. 68. Profile of the Mississippi river from Fort Snelling to rills beyond lake Itasca. Length about 500 miles.

over which the stream flows we have, associated, the two conditions which make for most rapid erosion. Even with one of these factors present, a vast amount of work is accomplished.

The Maturing of the Valley. Leaving to the next paragraph the numerous branches, let us look at the central stream flowing in that long, tortuous channel extending from lake Itasca to the confluence with the Minnesota river at Fort Snelling. Erosion at the outlet of Itasca is slight; past lake Bemidji, 30 feet; at Brainerd, about 30 feet; at Saint Cloud, 40 feet; at Anoka, again, about 30 feet measures the average depth of the river channel. For the future the carving must be slow because at a number of places the underlying crystalline rocks are bared; they are worn away only with extreme slowness even when the water flows at cascade speed.

The channel now formed has been made by the downward cutting of the river into soft material. It is still shallow and very narrow, because it is very young. Its width during its present history was at first that of the river at its high water stage; later it became much greater because weathering, gravity, and rain-wash are continually loosening and carrying downwards the material along the valley sides, placing it in the current of the stream for removal, and thereby becoming import-

ant factors in the complex process of erosion. Thus the form of the valley changes from its original V-shape to a broader type with terraces here and there along its sides. Figures 64, 65 and 66 illustrate this progress of change. The adjacent country shows a diminishing slope towards the eroding stream.

Fig. 69. The ultimate head of navigation of the Mississippi. The boat is 300 yards beyond lake Itasca in Nicollet creek, a tributary of the west arm. *Photograph by T. S. Roberts.*

Tributary Streams. The Mississippi, like every other river starting on a new land surface, has developed numerous tributaries. These result from the thousand and one inequalities. They drain every square mile of the basin, and in spite of every hindrance of swamp and lake and moraine, bring the run-off

waters to the central stream. Each tributary deepens and broadens its channel and cuts a meandering course. It overcomes obstructions by cutting through moraines, channeling swamps, and filling lakes. Finally, it lengthens itself by pushing back its head beyond the original divide, and therefore commits piracy upon its neighbor stream. Perhaps this neighbor stream, taking advantage of steeper slopes, in its turn plays the pirate. If so the divide becomes a zigzag line.

Each one of these tributary streams, as the Crow, the Elk, the Sauk, and so on, has its own still smaller tributary creeks and minor streams. All work is backward from the larger to the smaller streams. The minor divides become narrower and eventually will become lower. Many channels accelerate the down-cutting of the land, each stream adding to the volume of silt as well as water carried from the state.

Some Conditions of Flow. The topography of central Minnesota has not developed many cataracts or cascades. The Upper Mississippi in the one-third of its course between lake Itasca and the outlet of Pokegama lake, about 175 miles, falls but 150 feet, a descent so slight that it is almost unparalleled among large streams. As a rule, the head waters flow down sharpest descents and rivers show this curve of stream erosion, namely: The profile is a concave curve with the greatest curvature towards its source. There are many illustrations of this type of erosion curve among Minnesota rivers.

In the next 175 miles, from Pokegama lake to Brainerd, the descent is just about the same with two waterfalls thrown in. The river meanders to a remarkable degree. It has cut its V-channel, left terraces along its walls, and passed to its flood-plain stage. Over

Fig. 70. The first one-fourth mile of the Mississippi river.
Photograph by T. S. Roberts.

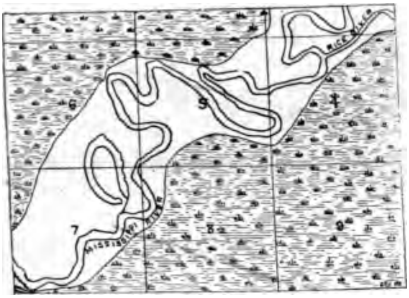

Fig. 71. The Mississippi river in town 47, range 23, showing meanders and oxbow lakes

this almost continuous bed of thickening silt it works its way with extreme slowness.

From Brainerd to the falls of Saint Anthony is the third length-division. This is the oldest in years of flow and the largest in water-volume. The bed rocks are several times exposed in rapids. The river's work henceforth is to be of a heavier type. The descent is 300 feet, or about the same as that of the two-thirds from Brainerd to lake Itasca. But the wear necessary to carve a deeper channel! With over 100 miles of the hardest and most resistant rocks, with a current above so slow that no abrasive silt can be brought to the work, baseleveling for the Upper Mississippi is accomplished already. And yet it is scarcely begun, for the power to baselevel depends on the contour of the drainage basin of the river.

Other Minnesota Streams. A glance at the drainage features of the state shows that every river save in the south exhibits the same evidences of youth as that just described. The Red river is a new stream. It can be but a few thousand years since lake Agassiz was drained by opening a channel through glacial ice beyond Winnipeg. The streams carrying away the surplus water of this great lake bottom drained the surface steadily downward from the outermost edges to the axis of the lake bottom. The Red river is so young that its banks are steep and crumbling. On

account of its low gradient, it meanders in a most tortuous course through the mud of the lake bed. That part of its course above Breckenridge is still in the midst of its preliminary work of establishing drainage by cutting down moraines and filling the beds of thousands of glacial lakes.

The Nemadji river basin on the eastern border of the state is an area of unusual interest. It lies in the bed

Fig. 72. The Mississippi river flowing in its recently cut Saint Anthony falls-Fort Snelling gorge. Near the Soldier's Home.
Photograph by A. S. Williams.

of glacial lakes Nemadji and Duluth. Its area is about 500 square miles. Before one standing in the valley, the horizon forms an even sky line. Below this the streams have cut into the soft clays and sands in sharply V-shaped gullies and valleys from a few feet to 200 feet in depth. To cross this basin at right angles to the course of the river would involve one in a series of most laborious climbs and descents.

With the draining of lake Superior from the former level of its surface of 1100 feet down to its present level of 602 feet, there were washed smooth and even beds of clay and sand whose southern edge stands nearly 500 feet above the present lake. During the time the Nemadji and its branches have flowed across this surface, channels have been cut which, in their upper stages, are gullies and ravines, in their lower, valleys and gorges. The soft rock is continually slipping down their steep sides to the bottom, where it is taken by swift flowing streams and carried to lake Superior.

The Blue Earth river, while somewhat older, is gathered in a region not physiographically different

Fig. 73. A valley near Clear Creek, Nemadji valley.

from the Nemadji basin. Glacial lakes Minnesota and Undine with their beds of sands and clays afford excellent material for stream sculpturing. The valleys are gorges before the Blue Earth joins the Minnesota, while towards their sources they are ravines and gullies. The hundreds of streams draining the slopes along the

northeastern sides of the great Coteau show many interesting stages of stream erosion similar to those mentioned above.

These are only examples selected from widely distant parts of the state to show that the processes are constant and universal. Every stream in these newer portions of the state, whether large or small, will afford a good illustration of the uninterrupted progress of events and the steady aging of the surface features of the commonwealth.

But one must not expect too much. We read of baseleveling; Minnesota was baseleveled in earlier periods of her history. We read of rejuvenescence; with Minnesota far inland, her borders scarcely more than 600 feet above the sea, and her rivers scarcely begun in their rejuvenation of the surface, no future baseleveling can be looked for until changes shall have taken place so profound as to move the continent.

CHAPTER XVII.

THE STORY OF A WATERFALL.

A waterfall—Saint Anthony falls—The history of their recession—The rate of recession—Minnehaha falls—The rock wall at Minnehaha—Other waterfalls in southeastern Minnesota—Northern Minnesota.

A WATERFALL is the fall of a stream of water from an overhanging precipice of rock into a lower bed. This lower stream-bed is usually a different rock stratum. Yet this definition does not involve the age of the bed, the quantity of water, or the kind of rock over which it flows. Minnesota waterfalls are in some instances almost what the Germans would call "dust of the brook," since the stream of the top soon becomes separated drops, and these reach the underlying pool but little less than spray. There are others where beautiful and continuous sheets of water fall without a break. There are waterfalls within Minnesota over rocks of every geologic age represented in the state,—Archean gneisses, Keewatin schists, Keweenawan volcanics, Cambrian sandstones, Ordovician and Devonian limestones, and glacial drift.

The character and history of every waterfall is a story peculiar to itself, but general principles and conditions are seen in all, and a single illustration may explain these for many well-known waterfalls.

Fig. 74. Bridal Veil falls. A rivulet flows over the rock ledge into the Mississippi river gorge one mile below the falls of Saint Anthony.

Saint Anthony Falls. 15,000 to 20,000 years ago some say it was not so long, a stream,—men now call it the River Warren,—flowed from lake Traverse through Big Stone lake, past New Ulm, Mankato and Fort Snelling, to the gorge now occupied by the Minnesota and Mississippi rivers. A great field of ice stretched across the state with irregular front. It was a waning glacier and had reached the vicinity of Fort Snelling in its retreat. The ice melting from this glacial front formed large quantities of water. This water, in Saint Paul, gathered into Lake Hamline and ran down the slopes through West Saint Paul into the Mississippi. Another volume flowed by a tortuous course into the RiverWarren several miles west. It wound right and left, scraping off glacial drift from the surface limestone until hundreds of acres of this underlying rock were laid bare. The

water began to gnaw upon the edge of the gorge of the River Warren at Fort Snelling, and cutting was soon manifest. A cataract swept over the brink of the falls, the soft white sandstone seen at Fort Snelling beneath the limestone was rapidly worn away. Blocks of limestone fell down into the chasm thus formed exposing the sandstone to still further erosion. More limestone was undermined. Again huge blocks fell into the abyss.

The History of Their Recession. The work thus begun was continued century after century and a gorge was cut past Fort Snelling steadily northward. Islands were formed in the main stream, which swung now to the right, now to the left, but continued its work of carving the gorge. We find many a little channel telling the story of a river's wandering within the area between Fort Snelling and Minneapolis. A notable island occurred where now stands the Soldiers' Home. There were two branches of the Mississippi, the one flowing and working along the present gorge of the river, and the other passing around the island to its right and helping to form the Minnehaha gorge. Here was a veritable Goat island as Goat island at Niagara falls is described today. One branch of the Mississippi was of full volume and possessed enormous eroding power, as do the Canadian falls at Niagara; the other was a smaller stream working with diminished power, and cutting its gorge at a much slower rate. As these two streams continued in their work the eastward stream wore rapidly, and in time cut past the head of the westward channel at a few hundred yards above the Soldiers' Home. The two branches of the Mississippi became one. The westward channel ran dry and since that time the island has been a simple depression in the landscape of this spot.

Time wore on; the gorge continued to be cut. After many years Father Hennepin visited Saint Anthony falls. These falls were then near where the Tenth avenue bridge now stands. This devoted man and lover of nature made a sketch of the falls and wrote his description of them with such clearness that their position can be traced at the present date. Explorer after explorer visited this region, attracted by the

Fig. 75. Falls of Saint Anthony in 1851, looking from Hennepin island westward. *Copied from plate P, volume II, Minnesota Geological Survey.*

legends and the facts of Saint Anthony, until Captain Carver came. He, too, described Saint Anthony falls. After some years the white man, having come to the state, began to plant his works upon the falls. The settlers soon realized that falls are not the permanent structures men are apt to regard them; they saw impending ruin. The power of the government was

invoked; a huge dike of masonry was placed within the sandstone behind the brink of the falls. An aproning of pine allowed the waters of Saint Anthony to slide down from the limestone brink with diminished force into a lower stream bed, the Saint Peter sandstone. Saint Anthony falls are no longer receding toward the sources of the Mississippi. Human agency intervenes and in this spot nature's processes are held at bay.

The Rate of Recession. The question is a natural one: What do we know of the rate at which Saint Anthony falls have receded from the bank of that ancient River Warren to the present site? Geologists and geographers have various methods of computing time. One is to calculate the work accomplished; another, to compute by observation from small accomplishment to large result. The last method is the one which was adopted by Professor Winchell for determining the age of Saint Anthony falls.

Father Hennepin visited the northwest in 1680. Until 1856, 176 years later, when the great dikes were placed behind the brink of the falls, the latter had receded 1,018 feet, or almost 5.8 feet per annum. Captain Carver came and saw and pictured the falls in 1766, or 90 years before the building of the dike. He witnessed the falls standing with their brink 606 feet below the present one. Hence the falls receded nearly 6.75 feet per annum during the intervening time. It is easy to compute by difference the recession from Captain Carver to Father Hennepin; in these 86 years the falls retreated 412 feet, or nearly 4.8 feet per annum. If the gorge from Fort Snelling to the present cataract be nine miles, the average of the three measurements named will give a period a little less than 8,000 years.

This estimate is on the basis of a great stream centering its force upon the cutting of a gorge less than 1,000 feet wide. The Mississippi river has done a vast amount of work in addition to gorge-cutting since it began its career at Fort Snelling. The sweeping away of thousands of acres of glacial till around Fort Snelling and in west Saint Paul; the wearing out of the side gorges cutting the Snelling reservation and Minnehaha park; the hollowing out of the basin now containing lake of the Isles and other lake gems, represent an amount of erosion which is simply enormous. This work must be added to the specific work of gorge-cutting. Hence, gorge-cutting must not be taken as the only result of water action as we survey in imagination the work of the Mississippi river, carrying steadily backward from its Fort Snelling brink the cataract first made known in its grandeur with Father Hennepin's tribute to his patron, Saint Anthony.

Minnehaha Falls. Let us go back for the moment and note the recession of Minnehaha falls. We have already spoken of the disappearance of the ancient Goat island of the Mississippi through cutting off the water supply from the western branch. Minnehaha creek from the west joined this west branch of the Mississippi a few hundred feet below the present position of the falls. It united its work of erosion with that of the west branch of the Mississippi so long as the two could keep together. When the Mississippi swung northwards, Minnehaha creek joined it from the west. At the point of separation was the beginning of Minnehaha falls. That this cataract spans fewer years in its recession than does Saint Anthony falls is evident at a glance. This gorge could have been but a few feet in length at the time the Mississippi destroyed

Goat Island the First. Accordingly, the age of Minnehaha is about one-half that of Saint Anthony.

The Rock Wall at Minnehaha. The conditions for a waterfall at Minnehaha are ideal. A formation of reasonably durable rock rests upon a less firmly cohering sandstone. The escarpment is of varying hardness.

Fig. 76. Falls of Minnehaha showing the rock conditions which make the falls possible.
Photograph by A. S. Williams.

At the top it is shaly, so that the waters, cutting the uppermost layers faster because they are softer, have formed a normal rapid; the harder underlying layers of limestone become the true crest of the waterfall. To a marked degree frost and ice aid gravity and rock-decay in cutting back the brink of the cataract. The sand-

stone below is so soft that it rapidly crumbles and floats or rolls away through the force of the current. That Minnehaha has worn so slowly is due to the small amount of water brought to the work of erosion. This amount, probably for hundreds of years, will not be increased. Measurements made from year to year in lake Minnetonka, the source of Minnehaha creek, show a steady fall in the surface of the lake. This means that for much of the year there will be no run-off from the lake Minnetonka drainage basin through the creek. This shrinkage is due, not to diminished rainfall, but to the demands of agriculture. The higher the state of cultivation, the more water the ground must have. Springs along the course of the creek may continue to furnish a small supply of water, but the Minnehaha falls of the future will be a disappointment to those who have read of the Minnehaha of the past.

Other Waterfalls in Southeastern Minnesota. The geologic conditions producing the falls of Saint Anthony and Minnehaha falls are repeated in many localities throughout the southeastern part of the state. There are other waterfalls in Saint Paul and Minneapolis. The Vermilion falls at Hastings and Minneopa falls near Mankato mark spots of rare beauty enjoyed by thousands. Along the Root river, the Rollingstone, and the other streams which find the Mississippi below Saint Anthony falls, old age and local conditions have modified the precipice-like character of the rocks; falls have degenerated into cascades and rapids.

Northern Minnesota. In northern Minnesota, the conditions of cataract building are notably different. It is not because the rocks are older—but they are: it is because they are of an entirely different type. Where a succession of lava flows occurs, the loose and porous

portions of the flow are eroded rapidly. A cataract-like character is developed where a succession of hard and soft parts of lava flows are in the path of streams. Garfield park, Duluth, shows a beautiful cascade of this type.

Again, dikes of igneous rock, cutting through schists or slaty beds, inject a rock extremely difficult to erode across the line of softer deposits. Pigeon

Fig. 77. Kawasachong falls at entrance to Kawishiwi river, northeastern Minnesota.
Photograph by N. H. Winchell.

River falls at the extreme northeastern corner of the state show this type of waterfall.

Again, bosses of granite intruding older rocks afford material slow to erode. Some of the most magnificent cataracts and extensive water powers of the state occur at such points. Couchiching falls at the foot of Rainy lake, and Partridge falls at the outlet of Cross lake. are good illustrations of this type.

Fig. 78. Lower falls of the Devil Track, three miles below Grand Marais.
Photograph by C. B. Hibbard.

Some waterfalls of Minnesota are due to the renewal of the drainage of the state. What the surface was before Glacial time must in part be conjectured, since the state has not yet been fully explored. The streams are mostly new; in many localities they have cut down their channels to the bed rock and come upon the buried ledges. Rapids form. Later, as conditions favor and work is accomplished, waterfalls develop: valleys also alternately narrow and widen; the streams become a succession of rapids, cataracts and waterfalls interposed between reaches of quiet waters and deep pools.

CHAPTER XVIII.

STILL OLDER STREAMS.

Definitions—Old channels—Southeastern Minnesota—Illustrations—A comparison—The Root River valley; the Chippewa River valley—Drowned valleys: the Root river; the Saint Louis river—Flood plains.

A RECENT WRITER of geography has classified streams as human beings are classified, into young, adolescent, mature, and old. In the case of streams this classification is based upon the amount of work they have accomplished and the fulfillment of physiographic processes to which they have attained.

A young stream is one in which the amount of work done is slight; in whose basin gullies are frequent and valley walls stand closely opposite each other, and along whose course are rapids, cataracts and waterfalls.

An adolescent stream has eroded much more than a young one; yet it is not up to the full capacity of the stream. Its gullies are developing into ravines, and ravines into valleys. Its cataracts and waterfalls are clearly defined.

A mature stream has well advanced its work of erosion. Waterfalls are near its headwaters; lakes have disappeared save as incidents in the flood-plain history, and it has begun that meandering, uncertain flow which points towards oncoming age.

At last the river is old. Its work of erosion is accomplished. Its basin is reduced to the lowest level to which the stream is capable of carrying it; it is merely leveling the divides by washing them into the valleys; it is depositing more silt than it is carrying away, because plants grow, die, and decay, and dust everlastingly accumulates. It makes more work for the next stream-generation than it is doing for it.

In another respect it is with streams as with people. There is no year when it can be said the river advances from its adolescent to its mature stage, or from maturity to old age. The gradient of the stream, like the rate of living, determines when maturity is reached. A fast gait drives to the goal quickly.

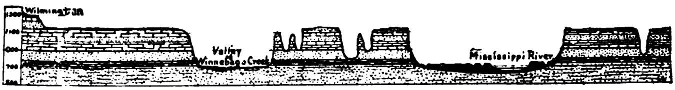

Fig. 79. Cross section from Wilmington through Jefferson to the bluffs on the Wisconsin side of the Mississippi river. Distance about 20 miles. Height of Wilmington above the sea 1,300 feet. A flood-plain is accumulating.

Old Channels. If one traverse the Mississippi valley, from the Iowa line to Fort Snelling, thence the Minnesota to Big Stone lake and the Saint Croix valley from Point Douglas northwards, the valley features are notably different from those seen in any other part of the state. Everywhere lies evidence of greater age. The channel between the right and left bluffs continually bordering the stream, is miles in width toward the south; the walls are generally rounded and smoother; rocks have been converted into silts; sands and clays remain while other substances have been floated away, and over the hillside surfaces a well developed flora has grown.

This is a mature valley. It has passed through the stage of deepening and terrace building, and is now existing in the stage of flood-plain formation. This is evidenced by artesian wells bored at LaCrosse and Winona, where the river silt is penetrated for more than 150 feet. The work of the river, as compared

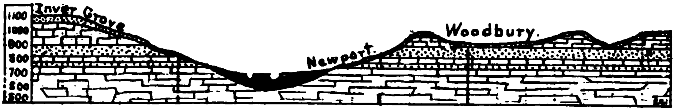

Fig. 80. Cross-section through South Saint Paul and Newport. Flood-plain about one and one-half miles wide and 147 feet deep.

with what is now visible, has been enormous. At one time, places now 450 feet high at Winona were more than 600 feet above the stream, with walls as abrupt and precipitous as are those of the Grand Canyon of the Colorado. Very different are the present features from those of a newly cut valley like that seen, for instance, by one standing at Fort Snelling and looking up the Mississippi as it flows through a new, narrow, clean-cut gorge and empties at one's very feet into the

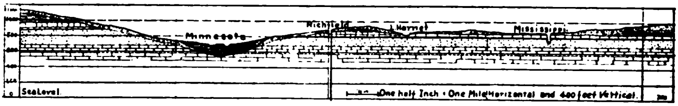

Fig. 81. Cross-section from Burnsville, Dakota county, through Richfield to the Agricultural College farm. The difference between the Minnesota River valley and the Mississippi gorge at the University is to be noted; the former is mature and the latter is very young.

old Minnesota-Mississippi channel cut for it before and during glacial time.

Southeastern Minnesota. That part of Minnesota which has been described as within the so-called "Driftless Area" is quite different from the rest of the state.

The slopes of the stream valleys are much gentler; the bluffs are more rounded. A soil covers the rocks; trees grow upon the hillsides; there are undulating divides between the streams, rather than broad level tracts. The Mississippi has become a sluggish, loaded stream; that is, it deposits material. It has cut a valley which at Winona was once 150 feet deeper than now, but is filled to that extent with silt. The river simply can not carry its load. The gorge walls, in future centu-

Fig. 82. A view across the Minnesota River valley near Vicksburg. Width more than one mile.
Photograph by R. D. Irving.

ries, will be lower than now, partly by the weathering of their tops, and partly through covering their bases by the further silting of the river. The tributaries which rise in the prairies flow at once down steeply sloping channels, reaching the level of the Mississippi flood-plain some miles away from the stream. The charming Winnebago falls from prairie to valley early in its course. Root river and its branches tumble into

their valleys at once. Rollingstone plunges down hundreds of feet and then flows in a more stately current to the broad flood-plain. The Whitewater, Zumbro, and other streams are no exception to the entire succession of tributaries from the Iowa line to the mouth of the Cannon river.

Illustrations. Many figures in the early chapters of this book will illustrate fully the physiographic maturity of this corner of the state. These by way of illustration may be recalled: Figure 9 called attention upwards to the clouds; yet on the ground a broad stretch of the Mississippi river from bank to bank is in full view; Figure 66, although diagrammatic, represents the general condition of the middle Mississippi, that part between its confluence with the Minnesota and that with the Ohio; the frontispiece, a view across Winnebago creek, shows in strong and beautiful lines the features of a stream in its vigorous days. In this chapter are figures which bring out strikingly the age relations of the stream as compared with streams in other portions of the state. They should be scrutinized that these relations may be seen.

A Comparison. Let us now look at two stream valleys, each of which is a type of its kind: The Root river of Houston and Fillmore counties and the Chippewa, a beautiful stream in the western part of the state.

The Root River valley is 1,700 square miles in extent. The rainfall within its area is about 30 inches per year, somewhat more than that of the Chippewa. The ground of one area absorbs moisture about as readily as that of the other. The valley of the Root river stretches westward from the Mississippi into Mower county, where the prairie lies 1,400 feet above

the Gulf of Mexico. The mouth of the river is 625 feet above the Gulf. In flowing 75 miles, the air line distance from source to mouth, the descent averages over 10 feet per mile. It must be borne in mind that both the Chippewa and the Root are much longer streams than the figures named would indicate. They meander as every stream does, and doubtless either one of them is more than twice as long as the air-line distance. Root river has been a much more rapid stream than it is now. Once its mouth was 150 feet deeper than at present. When the Mississippi filled its bed with its overload of silt, the Root was obliged to do the same. Two streams at their confluence must always be at precisely the same level.

The Root for many miles of its lower course flows through a valley from 250 to 500 feet deep. The walls of this valley stand far apart,—often quite two miles. The sides are old looking, rounded, more or less covered with grasses, shrubs and trees. The uplands and slopes are covered with a soil of degradation which gives evidence of the long time during which the rocks have been exposed to the attacks of the forces of erosion. The divides are well-rounded, yet gently sloping. The attack of the stream upon the high prairie plain is well advanced.

The Chippewa river is a recent stream. It empties into the Minnesota river at Montevido where its flood-plain has considerable width. Its sources are among the Leaf hills in the southern part of Otter Tail county, 1650 feet and more above the sea. Its drainage area is 2150 square miles chiefly within the prairie region. The descent from its ultimate source to the Minnesota river is near 700 feet. Many water powers of great local value are due to this fall. Within its basin and

drained by it are some of the most beautiful lakes of the state. Along its upper branches are many stretches of beautiful river scenery, wooded belts being an attractive feature. Below for some miles this stream runs through a valley varying in depth to 100 feet and less than one-third of a mile across until near the flood-plain of the Minnesota.

The Chippewa seems to have had its origin in the ice-fields of glacial time. The volume of water coming from melting snows cut a deep and permanent channel in the masses of till and modified drift laid down in the earlier stages of glacial retreat. The channel then made by turgid streams has been cut still deeper during post-glacial time. It now serves to drain scores of lakes and swamps, and carries off the surplus water of prairie rains. Other river channels and almost abandoned water courses of similar origin still are seen in this region. Hawk creek and Pomme de Terre river give evidence of much glacial drainage and a marked diminution in drainage vigor since post-glacial time was entered upon.

The most marked difference as one studies the two drainage basins is seen in the maturity of the Root river basin and the youth of the Chippewa basin. There are rounded land surfaces and direct water-courses in the former and scarcely a lake in the whole region. In the latter basin are angular valley walls, immature stream courses and scores of post-glacial lakes.

Drowned Valleys are those in which the land is slowly sinking. The crust of the earth is continually moving upward and downward. Nowhere is it stationary. We may be unable to see an appreciable change for hundreds of years, because the elevation or submergence is so slow that man's method of measuring has

not been sufficiently accurate to detect any difference.

When the movement is downward, land disappears beneath the water. This is noted through the filling of depressions up to a common level, that of the water of the region. As time goes on, the water encroaches farther and farther. The more uneven the land while sinking is in progress, the more islands there are and the more irregular the coast line. The water becomes sluggish at the mouths of rivers and deposits its silt before it reaches open water. These two conditions of sinking lands and enlarging mud flats are common characters of drowned valleys.

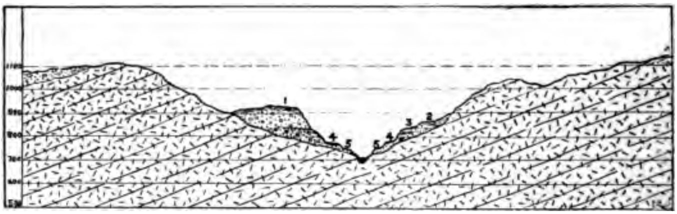

Fig. 83. Cross-section showing the terraces at Taylors Falls and Saint Croix Falls. They were formed during the sinking of the Saint Croix river to its present level. 1, the pic-nic ground, Taylors Falls; 2 and 3, street levels in Saint Croix Falls; 4, the business street of Taylors Falls; 5, lower terraces,

The Root river seems slowly sinking about its mouth. Hundreds of acres of marshy land have been formed here, and in its lower reaches. The river has been held back by the overloaded Mississippi and forced to drop its accumulating silt within its own flood-plain. The situation is suggestive that the Mississippi is slowly sinking about its headwaters and is becoming thereby weaker for transport.

The Saint Louis river from Fond du Lac to Duluth shows still more clearly the characters of a drowned

valley. Many acres on both sides of the channel are now water and marsh that were, long years ago, dry land covered with heavy timber. The river below Fond du Lac has so lost its power to transport that nearly all its silt is dropped before the channel is reached through which it flows into the lake. This causes the harbor to fill, and compels the United States government to expend thousands of dollars annually in dredging and

Fig. 84. A flood-plain delta. A tributary stream has cut a gorge and valley into the Wisconsin bluffs of the Mississippi river and deposited the material in the path of this stream. The current is unable to remove it and a delta-like accumulation results. Locality, opposite Red Wing. *Photograph by H. F. Nachtrieb.*

keeping it navigable. This expense is plainly because the river so fails to do its work that the government must complete it instead. Good authority estimates the sinking of the land as compared with the water-level to be about six inches a century at the head of lake Superior.

Flood Plains. If a river bring to any part of its

Fig. 85. The Mississippi river at the southern boundary of the state.
Photograph by C. B. Hibbard.

course more material than it can carry, it is spread out into an accumulating mass of fine silt, making bottom lands, or a "flood-plain." A flood-plain cannot be formed if the river maintain its work of transportation and carry to the sea all material imposed upon it. When for any cause its flow is slackened, its power is reduced; the workman who cannot keep his end is soon overwhelmed.

The Mississippi-Minnesota channel from La Crosse to Ortonville is rapidly forming a flood-plain. The cause lies certainly in the reduction of carrying power. What causes the reduction? Perhaps by a slow and steady sinking, only a very few inches in a century, the level of lake Itasca is becoming lower. If that is the case at the western end of lake Superior, we should expect it to be the case in the central part of the state. If there be any subdivision of the Mississippi within this state into torrential and flood-plain divisions, the separation lies at Fort Snelling. From that point to the Iowa line the river exhibits one of the most remarkable series of meanders, oxbow lakes, side channels, sloughs, swamps and cultivable stretches anywhere to be seen. In flood, miles of flowing water; in dry weather, the most magnificent expanse of vigorous plant life to be found within the state is a characteristic sight.

CHAPTER XIX.

DRAINAGE BASINS OF MINNESOTA.

The stream systems of Minnesota—Red river of the North—Saint Lawrence basin—Upper Mississippi basin—Minnesota River basin—Mississippi basin below Hastings—Iowa drainage—Missouri drainage—Adjacent sourccs.

THE SURFACE OF MINNESOTA is drained by three systems of streams, one reaching the sea in Hudson Bay, another in the Gulf of Saint Lawrence, and the third in the Gulf of Mexico. The first system, consisting of the Red river of the North and Rainy river, carries the water northward from 29,453 square miles. One half of this surface is prairie; the other half forest. The Saint Lawrence system, the second one, comprising the Saint Louis river, and the smaller streams that find their way into lake Superior, drains only 7,689 square miles. More than half the state, or 47,145 square miles, drains southward into the gulf of Mexico.

Red River of the North. The basin of this stream is the most interesting, topographically, of any portion of the state. It comprises 18,365 square miles. It reaches southward into Big Stone county, and eastward to the eastern portion of Beltrami county. Its highest point is in T. 142, R. 37, W., about 1,700 feet. The lowest point, where the river flows into Manitoba, is less than 750 feet.

Rainy River. This stream drains 9,675 square miles of northern Minnesota, reaching nowhere farther south than in the neighborhood of Lake Winnibigosh-

Fig. 86. Areas computed by Floy Hodgmire

ish. The lowest point of its basin in Minnesota is the level of lake of the Woods, 1,060 feet. The highest

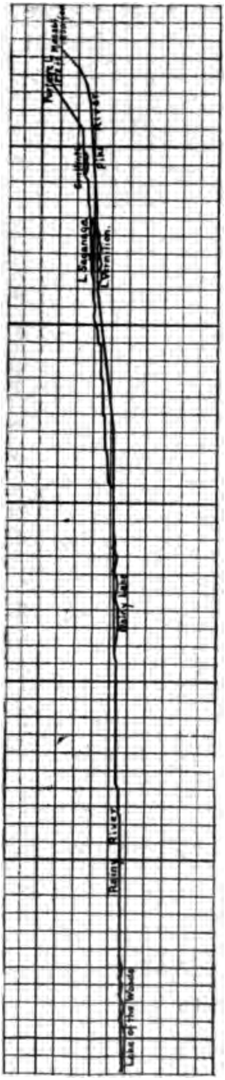

Fig. 87. Profile of Rainy river, being the International boundary from lake of the Woods to Gunflint lake.

point is more than 2,000 feet. It contains many lakes and is almost wholly wooded. The soil is fertile, yet there are thousands of acres of rocky and agriculturally barren land.

Saint Lawrence Basin. The lowest in this basin is the level of lake Superior, and its highest the summits of Misquah hills, 2,230 feet above the sea. The basin contains both the lowest and the highest water within the state, the latter in a small lake called Abita. It is thoroughly wooded and extensively rocky; often the hills and mountains are precipitous. Thousands of square miles of volcanic rocks lie in this basin. The Saint Louis and its branches drain 5,000 square miles, and the other streams 2,175 square miles. The head waters of this river are in T. 57, R. 11 W. The streams flowing into lake Superior along the Minnesota coast are remarkable for the size and number of the brook trout. This excellent food fish, as it lives in these cool streams and the waters of the lake, grows to a large size. It is here that Minnesota anglers find Paradise.

Upper Mississippi Basin. The upper Mississippi, that is, the

Mississippi basin from Fort Snelling to lake Itasca constitutes a well-defined area of 20,225 square miles. It is largely wooded, yet here and there small prairie tracts exist. During the last four decades many valuable farms have been opened up. This basin at its lowest point, Fort Snelling, is 688 feet, while the highest land is about 1,700 feet above the sea. It contains some of the largest lakes in the state, notably Mille Lacs, 201 square miles, Leech lake with nearly 200, and Cass lake with over 100 square miles. Within

Fig. 88. Sluggish drainage in the forest region of central Minnesota. The Mississippi river as it leaves lake Itasca.
Photograph by T. S. Roberts.

this area is the bulk of the famous Big woods of the state, and some of the poorest, as well as the richest farming land of Minnesota.

Minnesota River Basin. This basin, of almost the same size as the Upper Mississippi, possesses certain physical characteristics quite opposite. Its lowest point is the same, 688 feet at Fort Snelling; its highest point is just across the line in South Dakota, full 2,000

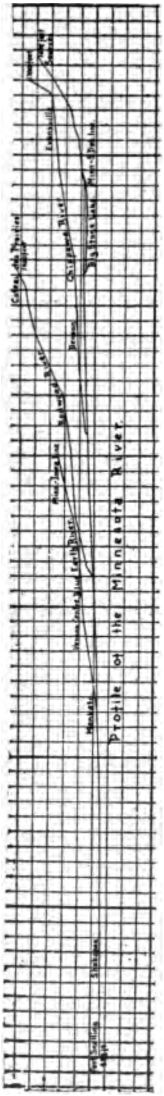

Fig. 89. Profile of the Minnesota river and its principal branches. The highest sources are those of the Redwood river at the crest of the Pipestone county Coteau.

feet above the sea, upon the great Coteau. There is but little timber within this drainage basin. A narrow belt of hardwood forest stretches from the Big woods southwest beyond Mankato. The remaining area is almost uninterrupted prairie. To be sure, along the streams and on the leeward side of many of the lakes, are small clumps of trees; yet, as a whole, the Minnesota is essentially as much a prairie basin as the upper Mississippi is a forested one. The ease with which farms can be broken and brought into cultivation explains why the Minnesota valley is occupied by a much larger population than the upper Mississippi.

The rainfall of this portion of the state is sufficient for the maintenance of a forest population when other conditions will permit trees to grow. Another fortunate feature is that, as a region of gentle slopes, it cannot be a region of terrific floods. Records of destruction from this source, either in the upper Mississippi or the Minnesota drainage area are, for a large river basin, unusually rare.

Saint Croix Basin. The Saint Croix river as it joins the Mississippi river at Point Douglas, brings waters gathered from some 12,000

square miles, of which 3,125 lie in Minnesota. Interesting tributary streams drain this surface into the Saint Croix. The Tamarack, taking its rise in Wisconsin, is of some importance. The Kettle river drains an important district, and in its erosion has disclosed valuable rocks. Particularly to be mentioned is the pink sandstone at the town of Sandstone. The Snake river, meandering through eastern Central Minnesota, draining nearly two thousand square miles of surface joins the Saint Croix river only 1½ miles south of the mouth of the Kettle. Sunrise creek may be mentioned here, because some geologists believe that its bed carried the waters of the Saint Croix before the vicissitudes of Glacial time drove that stream to take up the enormous engineering problem of cutting the Dalles of the Saint Croix.

Mississippi Basin Below Hastings. In the southeastern corner of the state are many streams flowing into the Mississippi. The Vermilion at Hastings has, for a small stream, done a great amount of work. The Cannon river near Red Wing is a larger stream than the Vermilion. Its accomplishment is also greater. The Zumbro and Whitewater rivers are both interesting in picturesque scenery as well as in the amount of work accomplished. The Rolling stone, coming from the prairies through a most charming valley to Minnesota City, is fittingly named. The Root river, draining hundreds of square miles, is probably the oldest stream lying wholly within the commonwealth, while Winnebago creek can nowhere be excelled for delightful and restful scenes. These streams, from Hastings southeastward, drain 6,260 square miles.

Iowa Drainage. Two streams of some importance

within the bounds of Iowa have their sources in Minnesota. The first is the Cedar, which rises in the southern part of Dodge county and flows through Austin to the state boundary. It is somewhat monotonous in its physiographic features, yet aided by the initial streams of the upper Iowa river, which also rises in this county, it drains 1,165 square miles.

The other stream is the river Des Moines, which rises in the southwest quarter of the state and drains 1,847 square miles. This stream affords outlet to many lakes,

Fig. 90. Sluggish drainage on the prairies. The region is so nearly level that this stream has not cut a distinct channel in its whole existence as a factor in the drainage of Freeborn county.
Photograph by P. D. McMillan.

flows past several flourishing towns, and becomes, before it joins the Mississippi, a stream hundreds of miles long, draining thousands of square miles of the best agricultural region of the middle Mississippi valley.

Missouri Drainage. Finally, in the southwestern corner of the state, there lies an area which is drained into the Missouri river. Its extent is 1,505 square miles. Its streams carry the waters from the western

slopes of the great Coteau des Prairies and drain an area of quartzite rocks.

Adjacent Sources. An ideal place for a prairie park lies in the Coteau des Prairies to the southeast of lake Benton, where, within an area of a few square miles are the headquarters of Rock river flowing into the Missouri, Redwood into the Minnesota, and Des Moines into the Mississippi.

Great canoe routes from lake Superior to the Mississippi river lie through those streams whose sources are so near together that portages of one or two miles only will take the voyageur from one basin to the other. Indians utilized these routes of travel. A canoe can be taken from the Mississippi to Rainy river where these two drainage basins adjoin in the vicinity of lakes Bowstring and Winnibigoshish. With equal facility were the aboriginal inhabitants accustomed to pass from the Red river of the North into the Mississippi through Big Stone lake and lake Traverse. At certain seasons of the year, the divide at Browns Valley has been covered with water, and white men have essayed the channel with their boats.

In prehistoric times well-defined routes of travel existed between the middle Mississippi and lake Superior. Evidences of early man have been found in Minnesota, as well as in Isle Royale, northern Wisconsin, and the upper peninsula of Michigan. The principal routes of travel in those times were through northwestern Wisconsin, and along the Mississippi and Saint Louis rivers.

CHAPTER XX.

THE ECONOMICS OF STREAMS.

Climatic conditions—Climatic averages for the upper Mississippi valley—Fertility of soil—Flow of water—Waterfalls—The reservoirs—An illustration—The reservoirs enumerated—Facility for migrations—A stream for study—For further reading.

Streams and their environing valleys have exerted a more potent influence on the advancement of civilization than any other one factor. The Nile, the Euphrates, and the Mississippi show convincing proof. While the reasons for this are various, the dominant forces are climatic conditions, fertility of soil, the flow of the water, and facility for human migrations.

Climatic Conditions. So far as this factor is effective in Minnesota, it seems to lie in the protection against winds and driving storms, afforded by overshadowing bluffs and the higher temperature incident to lower altitude. Height above the sea always conduces to colder climate; in this latitude every 300 feet difference in altitude changes the average annual temperature one degree. Thus the difference between the Mississippi river bottoms at La Crescent, Winona and Wabasha, and the prairie cities, Austin, Rochester and Owatonna, must be at least 2° annual average. There is also, according to the records, a difference of at least six

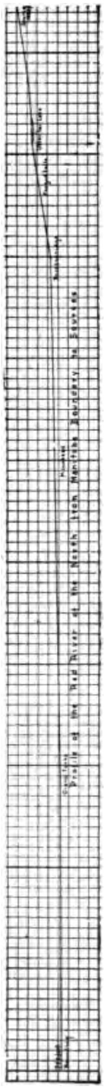

Fig. 91. Profile of Red river of the North. From the International boundar to its sources. Distance over 500 miles; descent from the sources to Breckenridge 700 feet; from Breckenridge to Saint Vincent about 200 feet.

inches rainfall per annum, that of the uplands being much the greater. The cooler prairie winds much more effectively squeeze the moisture from the air; so, too, they accelerate the process of evaporation. It must be due in no small degree to a warm, sunny outlook that such magnificent orchard and small-fruit crops are raised beside the Mississippi in southeastern Minnesota.

Climatic Averages. In the upper Mississippi basin climatic conditions become a little more strenuous. The rainfall is practically the same, varying not more than an inch or so in the two regions. The average annual temperature does not vary more than the latitude would suggest since there is no high land and no particular difference in the altitude above the sea. The average annual temperature for the entire Mississippi basin is 40.03° and the winter temperature is 20.6°. February is the coldest month; its average for the past 5 years is 7.6°. January is next with an average of 9.°. This is a long way from polar cold.

Fertility of Soil. The richness of soil on river bottom lands is proverbial. In Louisiana a crop of 70 tons of vegetable growth has been cut from a single acre in one season. But the growing season is several weeks longer in Louisiana than in Minnesota. Yet

a moment's reflection will convince anyone that in Minnesota, a much larger crop can be grown on Mississippi river bottom land than on the adjoining prairies. The fineness of material, the right admixture of organic matter, and the perennial supply of moisture all tend to produce a luxuriant growth of vegetation from royal timber trees down to the most noxious and persistent weeds. In such situations the heaviest crops can be grown and the densest population maintained. The bottom lands and lower slopes of the Mississippi and Minnesota river valleys are remarkably rich; they contain the garden spots of the state. Along these water-ways the state was first known. It was here that homes were established from which settlers extended their holdings and soon swept across the prairies.

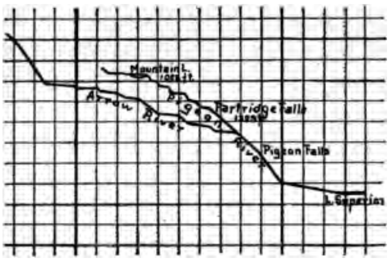

Fig. 92. Profile of Pigeon river and Arrow river. A series of lakes, rapids, cascades and waterfalls.

Flow of water. All streams in their everyday existence pass through three stages—valley cutting, terrace building and floodplain accumulation. The first suggests accelerated flow and rapid downcutting through the rocks which confine the stream; the second a lagging yet still energetic current, and the third inability to carry forward the load already taken up. Terraces are formed and then slowly covered; rocks are cut down and their edges slowly buried.

Waterfalls. Waterfalls and rapids are the most conspicuous elements when we turn to the economic

aspects of streams. Such features are comparatively common in this state. They afford waterpower for every form of manufacturing industry. The sum total within the state is enormous. It is measured by the unit called a horse-power, abbreviated 1 H. P. One horse-power means the power necessary to raise 33,000 pounds one foot from the ground in one minute of time. Waterpower is the great universal, primary source of mechanical energy. Running or falling water moves a wheel or other motor placed in its chan-

Fig. 93. A small stream in a region of such sluggish drainage that no valley can be cut. A hay meadow in the distance,
Photograph by P. D. McMillan.

nel, and the movement is transmitted by gearing or bands through a system of machinery. Engineers have now so perfected the methods of harnessing water that a systemof motors placed in a comparatively gentle stream will catch and transmit a surprising amount of power. But it is when Saint Anthony falls, Saint Louis River dalles, Coutchiching falls, and other great cataracts are confined that great

results are secured. In every part of the state some rate of running water may be utilized and power conserved. The total possible horse-power is several hundred thousand. The Mississippi river, in falls and rapids between Anoka and Saint Paul, has a horse-power estimated at 60,000; with important strength at Saint Cloud, Sauk Rapids, Little Falls, Grand Rapids and other localities, the power yet to be developed is very great. Rainy river between Rainy lake and lake of the Woods has 60,000 of which Coutchiching falls are the most magnificent factor. Saint Louis river between Cloquet and Fond du Lac has a power estimated at not less than 150,000 H. P. These few figures indicate some of the important centers of future industries.

Fig. 94. Pigeon River falls. A descent of 70 feet over a dike of igneous rock cutting through the sedimentary rocks of the region.

The Reservoirs. The United States government is constructing and maintaining a system of reservoirs for impounding the waters of several large lakes situated about the sources of the Mississippi. These reservoirs constitute a unique and important feature of the flow of water for this stream. Their purpose is to maintain a more equable volume. By holding back the surplus waters of melting snows and heavy rains the dan-

ger of overflow and destruction by surging floods is reduced to a minimum. Navigation during the dry season is aided by a partial opening of the gates, and manufacturing interests can depend upon more constant power, a very necessary condition of its successful use.

An Illustration. The Winnibigoshish reservoir dam is built across the Mississippi river at the foot of lake Winnibigoshish. It raises the water of the lake eight feet above the natural level and enlarges its area from fifty square miles to more than seventy-five. When

Fig. 95. Coutchiching falls. Probably more water runs over this cataract than over any other in the state.
Photograph by C. J. Rockwood.

the reservoir is full there are added over 16,500 million cubic feet to the water held in the natural lake. But the surface conditions admit still another six feet being added to the height of the dam. Should this be t, the water surface will be increased to one hund- fifteen square miles, and another 16,500 million ded to the stored water, giving 33,000 mil-

lion cubic feet as the capacity of the completed reservoir. Now let the figures be arrayed: For calculating power, the flow of water at the falls of Saint Anthony is estimated at three-tenths of a cubic foot per second for each square mile of the area drained. This area, see figure 86, is 20,225 square miles above Fort Snelling. From these data it is computed that the water daily passing Minneapolis averages more than 524,000,000 cubic feet.

Therefore, were all other sources of supply completely to fail, the water to be impounded in the completed Winnibigoshish reservoir is sufficient to furnish a supply equal to the daily average flow at the falls of Saint Anthony for more than two months. And this is but one reservoir in the system instituted, maintained and being developed.

The Reservoirs Enumerated. 1. In addition to Winnibigoshish reservoir there are at present the following located on tributaries of the Mississippi:

2. Leech Lake reservoir, raising Leech lake throughout its one hundred and sixty-five miles of surface three feet above its natural stage. This can, in the future, be raised still higher.

3. Pine River reservoir, raising the water in Cross, Pine, Daggett, Rush, Whitefish, Trout and Hay lakes to different heights above their natural levels. The area is large.

4. Pokegama Lake reservoir, dam several feet high and area about ten square miles.

5. Sandy River reservoir. The dam raises the water in Sandy lake ten feet or more; area of Sandy lake and tributary waters, nine miles.

Facility for Migrations. The story of the Nile valley has been told many times. It is the story of old civilizations following one another in steady procession. They existed because the conditions were perfect for the maintenance of large numbers of people. The climate is mild, soil rich and yearly re-enriched by the over flow of the river. The facility for the movement of every product of human strength and inventive genius is unsurpassed.

Had it not been for the Mississippi river and its

Fig. 96. Bridge across the Mississippi river at Red Wing.
Photograph by H. F. Nachtrieb.

branches it is safe to say that the heart of the North American continent would even now be a wilderness. Certainly, Minnesota would not be the flourishing commonwealth she has become, were it not for the streams. The early explorer pushing into unknown lands saw vistas of great things and then set vigorously about making his dreams living realities. Towns were founded beside the streams at long distances apart. From Fort Snelling as a centre because typical of power, Saint Peter, New Ulm, Fort Ridgely, Minnesota Falls, and Ortonville were founded; so, too, were Anoka, Saint Cloud, Little Falls and Brainerd; and again, Point Douglas, Stillwater, Marine and

Taylors Falls. From Fond du Lac, the original Duluth, grew Cloquet before the wilderness beyond was attacked. Then through the long and devious channels of small streams and over wearisome portages *voyageurs* and hunters pushed forward until the larger streams, more stately forests and far-stretching prairies of the Mississippi basin were attained.

A Stream for Study. As a pedagogical suggestion an additional use to which streams may be put is mentioned. Every stream whether large or small presents an epitome of water's work upon the land. Its flow so varies that, within a short distance of almost any Minnesota school house, every phase of a current can be seen from the waterfall to the slow-moving meadow pool. The current may be searched for its swiftest part and the position of this with relation to the curves of the stream both outward, convex, and inward, concave, may be observed. This observation should make clear the fact that the current has a greater curvature than its channel.

This observation brings the transport of material under examination. Along the stream bed lie bowlders, pebbles, gravelstones, sand and clay. They will all be found to sustain a certain relation to the rate of the current, the form of the channel and the source of supply. These three factors will be found potent, yet in varying degree, in forming rapids, accumulating sand bars and spreading out flood-plains.

If a stream be traced for two or three or more miles the widening of the valley down stream cannot fail to command attention. The queries will arise: What proportion of this stream's load comes from its higher sources? What from its stream bed? and finally what from its adjacent slopes by wash and creep?

In the next place, indications pointing to the youth adolescence, maturity or age of the stream will be sought out. Certain clear and well-defined characters mark each period in a stream's life-history. For the greater part of Minnesota, the birth of streams dates with the waning and close of the Ice age. Most streams are in their period of youth and the associated land forms often extremely immature. In youth, changes are rapid and strong; often notable progress can be observed within a single decade; stages now and those fifty years ago will, in many a locality, show marked advance.

In connection with field study let the reader pass in review the chapters of this book discussing streams. The illustrations have been selected with care. In this association the reader can best use them by placing figures 70, 88 and 93 at the beginning of the series and figure 85 at the close. Let all the rest be inserted at fitting places between these two extremes.

For Further Reading: The study of streams is of prime importance to him who would know geography. Much descriptive of them lies scattered through the reports of the geological survey of the state under "*Drainage*" and "*Topography*" in the several county descriptions. Of more general application are the following in volumes I, II and IV of the final report.

Young drainage: Blue Earth county, vol. I, pp. 415-419; Itasca county, IV, 166-168.

Young developing from glacial: Swift and Chippewa counties, II, 206-208; Carleton county, IV, 1-3.

Transition from old: Dakota county, II, 62-65.

Old drainage: Houston county, I, 207-211; Fillmore county, I, 270-277.

Relation of underground waters to streams: Winona county, I, 236-245, Goodhue county, II, 20-28.

The Upper Mississippi river: Hubbard and Cass counties, IV, 93-95; Beltrami county, IV, 135, 136.

The recession of the falls of Saint Anthony: Hennepin county, II, 313-341.

CHAPTER XXI.

FORMATION OF MINNESOTA LAKES.

A lake defined—Distribution of lakes—Classification of lakes—1, glacial lakes. 2, Silted river lakes; lake Pepin; Oxbow lakes, 3, lakes due to rock-faulting—Number of lakes.

A lake is a body of water, naturally enclosed, which cannot be considered as an arm of the sea.

Lakes constitute one of the most interesting and striking features of Minnesota scenery. They typify natural beauty of the highest order, and their use in cultivating love of the beautiful contributes one of the highest elements of true education. There are many points of elevation, standing upon which one may see literally scores of lakes lying in different directions. Every farmer considers his land more valuable if it slope down to the shore of a deep, clear lake; every village considers its situation ideal when it lies along a beautiful lake shore.

Distribution of lakes. Lakes are not evenly distributed. A map will show that certain portions of the state, notably the southeastern, contain very few lakes; the Red River valley shows also a remarkably sparse distribution. The reason for this in the latter case is that the valley itself is the bottom of a lake

Fig. 97. A farm beside a lake. "Every farmer considers his land the more valuable if it slope down to the shore of a deep, clear lake."

once much larger than the state.

Were one to undertake a journey in which it is planned to see the greatest number of Minnesota lakes, he would enter the state from Wisconsin at Taylors Falls. Going southwest to Minnetonka, he wonld pass some beautiful lakes, for Chisago lakes, White Bear, Bald Eagle and many others would be on his way. Turning now almost a right angle, and traversing in a northwesterly direction Wright, Meeker, Kandiyohi, Pope, and Douglas counties, he would finally reach Fergus Falls nestling in the heart of the Leaf hills. Here is the famed Lake Park region of North America. Hundreds of lakes would be seen on the way. Turning

Fig. 98. Map showing the distribution of lakes in Central Minnesota about the head waters of the Mississippi and the Red river of the North. After one prepared by O. E. Garrison for the Minnesota Geological Survey.

once more and, in a course nearly parallel with that by which he entered the state, making his way towards Hunters island and Ontario, he would pass literally thousands of lakes in Ottertail, Hubbard, Cass, Itasca, Saint Louis, Lake, and Cook counties. Nowhere else in the whole world could one see such a remarkable diversity of beautiful water expanse, green slope, and winding stream as in this journey.

Classification of Lakes. The student of lakes soon discovers that, in origin, different lakes are due to the play of quite different forces. As examples, compare

Fig. 99. The lower end of Big Stone lake, near Ortonville.
Photograph of Mrs. H. R. Burnell.

lake Pepin with lake Minnetonka, Minnetonka with Rainy lake, Rainy lake with Hungry Jack lake. We can classify them somewhat as follows:

1. Glacial Lakes. These are of two kinds, morainic, and bedrock lakes. The great glaciers brought high masses of debris and distributed it unequally over the surface. In the depressions of the material thus left, waters gathered from the surrounding higher lands. They gradually silted fine material into the

bottom and made it water-tight from the deepest point gradually up the slopes until the lowest point in the rim of the depression was reached. This outlined the lake, which is called from its situation, morainic.

These lakes are numerous wherever the surface is rough and rolling and of morainic origin. We shall find them in the Coteau des prairies; in the region around Minneapolis, and thence northwest into the Leaf hills; in the rolling belt from Saint Paul southward to Iowa; around the head waters of the Mississippi; and hundreds more in many portions of the state.

Again, the glaciers carved basins in the unequal

Fig. 100. Lake Sisseton, one of the Martin county chain of lakes,
Photograph by P. J. Kennedy.

rocks, and in these basins waters gathered until a point of overflow was reached upon the rim of harder bed-rock. These represent almost the entire removal of glacial debris, while the morainic lakes described its maximum of accumulation.

The bed rock lakes are those where the drift is so thin that the lakes rest upon the bed rocks. The necessary conditions for these lakes are an abrasion of the surface, a heavy accumulation of ice, and a very complete removal of rock material. We find these conditions most complete in the northern portions of the

state. Lake of the Woods, 1,500 square miles in extent, of shallow depth and carrying thousands of islands, is a conspicuous example of this type. Rainy lake, embracing nearly 350 square miles of a maximum depth of 110 feet, and said to contain 500 islands, is another. Basswood lake, lake Saganaga, and many others in their chain, are most beautiful examples. All these are on the International boundary. Others of this kind lie wholly within the state. Rock bound

Fig. 101. Lake Itasca showing Schoolcraft island discovered in 1832.
Photograph by T. S. Roberts.

bottoms and shores, clear, cold waters and many interesting islands, make these lakes truly charming.

2. Silted River Lakes. Rivers form lakes by a silting process. Confluent streams bring debris into the channel of the river in such quantity and of such coarseness that the current cannot remove it. The result of this damming of the waters is the formation of a lake. This formation continues until the area cov-

ered by the waters is filled with infloating silt, and an alluvial flood plain is formed. Several examples of this type of lake may be noted. Lake Pepin is the most conspicuous.

Lake Pepin. The Chippewa river rises in north central Wisconsin. It drains 8650 square miles, and flows with vigorous current to its confluence with the Mississippi at the foot of lake Pepin. Its volume is not nearly so great as that of the Father of Waters. In times of flood its banks are full. There are no lakes or other settling basins along its course, so its loads of silt are carried down to the very mouth. Its carrying power is enormous compared with that of the Mississippi. Let us see: Where the two streams unite, they are at the same level. Ascend them. At Saint Paul, 68 miles away, the Mississippi is only 20 feet higher than lake Pepin, a descent of only 3½ inches per mile and for the last 25 miles of this distance, it has almost a level surface through lake Pepin. Up the Chippewa river 62 miles is Chippewa Falls, 175 feet above lake Pepin. Here is a descent of 34 inches per mile, ten times as much as the Mississippi descends, sufficient to make a current several miles per hour—swift enough to roll along pebbles. All the debris gathered up is deposited squarely across the Mississippi's course. That slow old stream can do nothing but rise up and flow over it; and this it has invariably done as load after load of rock-waste has been dumped in its channel until its waters set back to the Cannon river, 30 miles from the mouth of the Chippewa. But the Cannon and other tributaries have poured their silt into the head of lake Pepin until it is filled to the condition of a succession of mud flats for more than five miles. It is a question of time only when lake Pepin will be an

ordinary channel of the Mississippi winding restlessly through a flood plain.

In its struggle with the Saint Croix river at Point Douglas, the Mississippi is the victor, not the victim. A descent in 25 miles from Fort Snelling gives the latter stream a fall of 20 feet with all the carrying power therein implied, while the former stands at one level for miles in lake Saint Croix.

Lac qui Parle river in the fifteen miles before it becomes absorbed in the Minnesota, falls 90 feet and silts the latter stream into charming Lac qui Parle, the "lake that speaks" in bewildering echoes.

Oxbow Lakes. A large stream meandering over its flood plain is continually cutting for itself new channels. As these are formed, water stands in the abandoned loops. From the peculiar shape thus assumed the loop lakes are called Oxbow lakes. Such lakes form natural moats around tracts of the flood plain, and so they are sometimes called moats. An almost constant succession of this type of river-silted lakes is seen between Ortonville and the Iowa line along the course of the Minnesota-Mississippi river. From the confluence of the Saint Croix to the Iowa state line they are more than a sucsession; two or three can be counted in looking across the flood plain at many a point.

3. The third type of lakes is due to rock-faulting or to rock-folding. Great areas of the earth's crust are cracked apart, thrust against each other, uplifted unequally, or squeezed together until they fold into great wrinkles. Thereby depressions result in which waters accumulate and form lakes. The rock-faulting of northeastern Minnesota occcasions hundreds of lakes; rock-folding and rock erosion produce others. Their

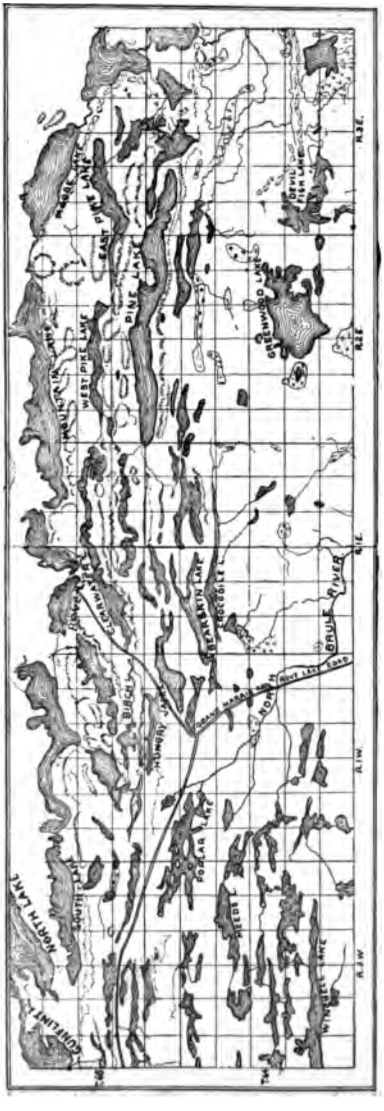

Fig. 103. Lakes of northeastern Minnesota, showing the form peculiar to this portion of the state. Taken from township plats.

characteristic feature is the long narrow shape. Lake Winchell, for instance, is nearly six miles in length, and nowhere, save in small embayments, is it more than one-third of a mile in width. Mayhew lake, over four miles in length, and No Name lake, more than three miles, have a width nowhere greater than the fraction of a mile.

Pine lake is a type or these lakes. It lies in a long, narrow valley whose north side slopes gently and whose south side is precipitous. The water surface is in no place more than one-half mile wide, but its length is more than eight miles. The outlet

is eastward, and ultimately through Pigeon river into lake Superior from an altitude of 1465 feet. As fishing ground this lake has no superior in all northeastern Minnesota. Its shores are beautifully rocky, bearing the characteristic vegetation of the region, and every aspect of its environment is wild and attractive.

Number of Lakes. Once, no doubt, there were more than 10,000 lakes in the state. Now there may be 8,000. In 50 years there will not be 5,000. They are disappearing at a rate we do not fully appreciate. Note a few figures given by different authorities: A few years ago Otter Tail county, still the banner county in lakes, had 430 of these bodies of water, one enthusiastic authority counted exactly 1,059; Becker county claims a large number; Kandiyohi county counts 286, and Wright county 259. Hennepin and Ramsey counties are strikingly rich in lakes and lake scenery.

There are counties in which lakes do not occur. Soututheastern Minnesota is physiographically different from the rest of the state; hence its lake conditions differ widley. The southwestern corner is further removed from glacial time than is the northeastern; Its lakes bear many evidences of greater age. This circumstance is in accord with all other physical features pertaining to these landscape gems.

CHAPTER XXII.

DEFORMATION OF MINNESOTA LAKES.

General conditions—Contour of lake bottoms—Obliteration of lakes—Lakes are good chronometers.

Traversing the lake district described in the preceding chapter and looking at the thousands of beautiful lakes, it is with pain that one realizes a lake to be the creature of a day in earth history. Thinking back to the study of glaciers and rivers, we impress ourselves anew that the present surface features of Minnesota are but a few thousand years old. The lakes can certainly be no older. In that imaginary journey undertaken to see many Minnesota lakes every age in the history of a lake is passed in review. Some are new: Such are bold and sharp in outline. Others represent more mature age: aquatic plants flourish along their shores and well out into their waters. Others are so filled with silt and growing weeds that boats can be no longer rowed, and, in the dry season, one can walk upon their bottom. Further, hundreds of swamps and hay meadows, outstretched along the drainage courses are proof of former lakes. Were further evidence needed, the oldest inhabitant stands ready to tell of the beautiful lakes, deep waters, uncounted ducks and

Fig. 103. Type of a waning lake. This was once a lake of considerable size but insilting and growth of vegetation have very nearly filled it. The zonal arrangements of the plants is clearly shown.
Photograph by C. B. Hibbard.

magnificent fishing of a few years ago.

Contour of Lake Bottoms. The bottoms of lakes are uneven in contour. Every lake has treacherous spots where it is dangerous to wade or even swim. If we note the contour of the country within the catchment basin of any lake, there will be seen a continuation of just such elevations and depressions. Sometimes they are of gentle slope, and elsewhere abrupt and precipitous, exactly like the bottom of the lake. The two areas, lake bottom

and basin contour, are simply parts of one and the same condition of glacial and stream deposition, or, possibly, of rock-worn surfaces. Islands occur in the lakes because knobs of unknown rock or piles of glacial

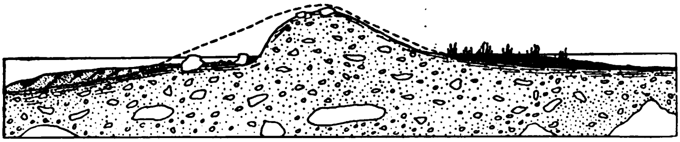

Fig. 104. Diagrammatic of a lake acting upon its shores. The waves upon the windward side are cutting into the glacial drift and by undertow carrying the material into the lake. On the leeward side wave wear is slight and vegetable accumulation considerable.

drift remain. Lake of the Woods is said to contain thousands of them; Rainy lake hundreds; in Lac la Croix, Basswood, and others, they may be counted by the score; while in the Lake Park region they are seen by the dozen. As a rule, the deepest portion of a lake is near its center. Some exceptions to this are noted, particularly in areas of morainic rock. Around the islands and along the shallow shores aquatic plants secure foothold and, year after year, renew a vigorous growth.

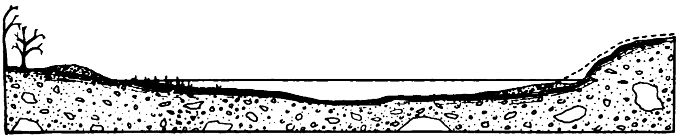

Fig. 105. Diagrammatic. A lake building a gravel ridge through the action of ice. The abrupt shore to the right is a barrier against which the ice rests, and by repeated shrinking and swelling, carries the gravel frozen into its bottom continually higher on the shore to the left.

Obliteration of Lakes. Step by step, with the formation of lakes begins and goes forward the process of their deformation. The silt which washes in is at

times of enormous quantity, and where the waters are shallow and the soil of the lake bottom adapted to vegetation, many forms of acquatic plants mature with remarkable vigor. In the shallower lakes this last obliterating process works with great rapidity. When the ice disappears in spring the warm sun of this latitude raises the water temperature to 70° or 75°, a point favorable for vigorous vegetable growth. Already hundreds of lakes have disappeared and rich, productive hay meadows have taken their place. This will be the fate of thousands more within the coming

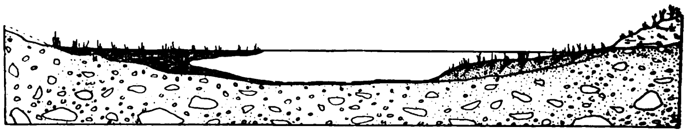

Fig. 106. Diagrammatic. The obliteration of a lake. On the right the lake bottom is covered with silt brought in by a stream and the wear of waves; on the left vegetation is developing a widening swamp which may be upon it's inner edge a quaking bog.

century. On every hand are transition marshes and fruitful hay meadows. In many places farmers are accelerating these processes by draining.

Lakes are Good Chronometers. It is frequently asked why lakes exist in Minnesota and Wisconsin rather than in Iowa and Illinois. The answer in part may be that this district is much younger than that; lakes once existing there have become silted and filled with vegetation until they are now the richest farming tracts of those states, a future condition most sure to come in Minnesota and northern Wisconsin.

The existence of lakes in any region is evidence of its topographic immaturity. They are formed by processes comparatively recent, if not still in operation.

Within this state, all lakes date back to the close of glacial time. They are obliterated with rapidity, as physiographic processes go. Silt fills them; water and

Fig. 107. A scene on lake Vermilion. Deformation by growing vegetation is is progress.
Photograph by N. H. Winchell.

marsh plants overgrow them; other vegetation covers the ground where once they were. In a short time most of them will be gone.

CHAPTER XXIII.

GLACIAL LAKES.

What glacial lakes are—Lake Minnesota—Lake Undine—Lake Hamline—Lake Upham—Lake Nicollet—Other glacial lakes—Conclusions.

There existed during the retreat of the ice northwardly across the state many lakes which have long since been drained away. These were glacial; that is, sheets of water formed by the melting ice and made to lie either between successive moraines of the glacial retreat, or against the ice thrown across some northward sloping land surface. From their very position and origin these lakes must have been of as transitory character as those which exist today. Further they could not all exist at the same time. Lake Minnesota, for instance, must have disappeared before lake Hamline came into existence, and this lake must have disappeared long before lake Agassiz reached its maturity. The ice invasion retreated from Minnesota along three different directions,—northeast, north, and northwest. Lobes thus penetrating into the state imprinted individual features upon its surface contour, each within its own area. Conditions contributing to the formation of glacial lakes during this waning period of their history were two: first, the relations of these ice streams to each other; second, and chiefly, the northward slope of the surface along the line of retreat.

While Professor Winchell has described twenty-six of these glacial lakes and mentioned several more, we have time to note only five or six.

Lake Minnesota. Persons living in Waseca, Faribault, and Watonwan counties have noted the remarkably level character of this region. Its general altitude is 1150 feet above the sea. If one take a map of Minnesota and trace the contour of 1150 feet, he will note in many places within it the accumulation of a non-indurated, glacial rock material which is quite stratified, thereby giving evidence of having been deposited by water rather than by ice. The point at which this belt of stratified material is interrupted lies along the Blue Earth river just west of Elmore. While the edge of this material can be distinctly seen in southern Faribault county, eastern Waseca, and western Watonwan, in an almost continuous line, quite like an ancient shore-line. it is entirely lacking along the northern side. This stratified drift marks the border of lake Minnesota where it stood barred by the wall of ice upon its north, and draining its waters southward past Elmore into the Des Moines river. When this ice wall became melted so that an outlet was *down* the Minnesota river instead of *up* the Blue Earth, the lake somewhat suddenly disappeared.

Lake Undine. In its disappearance there was a stage of halting. during which the surface of Blue Earth county, with a small embayment into Watonwan county, was readjusted at an altitude of 1070 feet, 80 feet lower than the general level of Faribault, Waseca, and Watonwan eounties. This level marks the bottom of lake Undine, a region named by Jean Nicollet in 1841 because it abounded in springs and streams, a fitting home in the midst of the trackless

prairies for the water nymph and her associates. These lake-bottoms of lakes Minnesota and Undine comprise one of the richest agricultural regions of the state.

It is believed that the outlet of lake Undine was from its northeastern corner across Scott and Rice counties. Working eastward under the very lee of the glacier the waters of the lake cut a channel still to be seen past Waterville, Faribault, Northfield and Cannon Falls into the Mississippi river. The existence of this

Fig. 108. Lake Undine. The approximate area of this glacial lake is to be calculated from the fractions of counties included within its limits. The outlet near the ice lobe to the right is indicated by the arrow. Lake Minnesota which preceded lake Undine extended approximately to the dotted line following the contour of 1150 feet. It emptied southward through northern Iowa into the Des Moines river.

glacial river may explain the great amount of erosion along the lower valley of the Cannon and the extent of the mud flats at the head of lake Pepin.

Lake Hamline was much smaller. It was con-

fined to the central part of Ramsey county. It must have lain, says Mr. Upham, between two lobes of glacial ice. Its elevation was at first 940 feet above the sea. With the erosion of its outlet, this elevation was shifted downwards to 850 feet, spreading out across the present gorge of the Mississippi to south

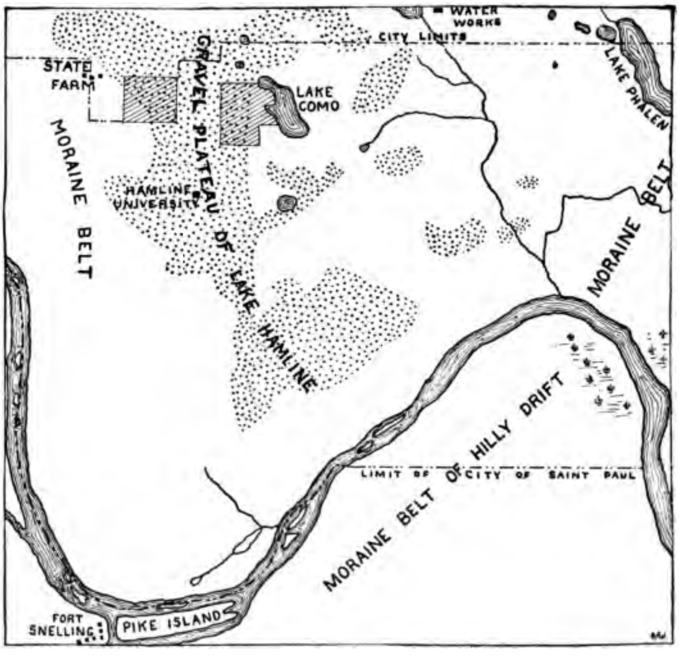

Fig. 109. Sketch map showing the position of lake Hamline by the extent of the dotted area or gravel plateau. Its position was between two ice lobes forming moraines as they interruptedly receded from each other and supplied the water of the lake by their melting.

Saint Paul, through Inver Grove into the Mississippi wherever this river at that time might have run. Proofs of lake Hamline are seen in the level nature of the

country where Hamline university now stands and in the modified or water-assorted debris which marks not only this particular area but that of several successive natural platforms in the descent from the level of Hamline to that of the West Seventh Street plateau of Saint Paul over which this drainage made its way to the great river gorge in the later stages of the glacial history of this spot.

Lake Upham. In the great level tract lying to the south of the Mesabi Iron range is spread out one of the most beautiful swamps in the state. Its area is hundreds of square miles. It comprises a considerable portion of the drainage basin of the Saint Louis and Cloquet rivers. Its north side rests against the southerly slope of the Giants range of granites and iron-bearing rocks, while to the east and south it is defined by the volcanics of a later geologic age. This area is so nearly level that the lake which stood upon it must have been very shallow.

Lake Nicollet. Around the head waters of the Mississippi river are seen the remains of a most interesting glacial lake. It accumulated at the parting of the two great lobes of ice-invasion from the northwest and from Lake Superior. The northeastern boundary consists of material pushed forward by the Rainy Lake lobe. The area of this lake, which Winchell names Nicollet in honor of the great explorer who underwent hardships and dangers to map and make known the geography of the northwest, was not less than 1500 square miles. It stood nearly 1400 feet above the sea, and drained southwest through the chain of lakes in Hubbard county into the Crow Wing river. Its area now segregates the head waters of the Mississippi chain of lakes as far as lake Pokegama.

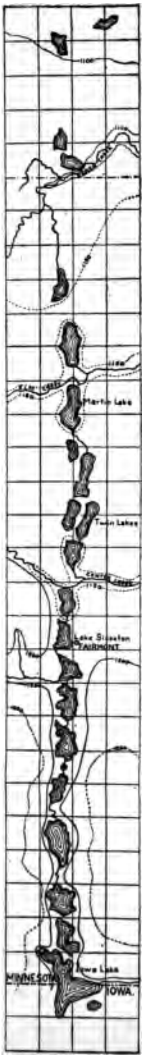

Fig. 110. Chain of lakes, Martin county. A drainage channel of glacial time.

It is needless to describe more of these somewhat obscure lakes save lake Agassiz, the most prominent geographic feature of this truly wonderful glacial time. This will be the subject of the next chapter.

The same general characters prevail in them all. Some were higher above the sea than those described, others lower. Generally the highest stood in the northeastern and southwestern corners of the state. The highest recorded altitude of such lakes is, I believe, 1850 feet, in the valley be tween the so-called outer and inner moraines which form the Coteau des Prairies of the southwest.

Glacial lakes were ephemeral. They were mere incidents in the progress of a far greater movement, one fraught with profounder consequences as we contemplate its results in the light of human interests. With the final retreat of the ice from the boundaries of the state, the last glacial lake disappeared from its history, save in recorded imprints in the land surface and resources of the commonwealth made possible.

Conclusions. Many glacial lakes were formed during the ice retreat from the south only to be obliterated when the margin attained to higher ground. A glance at the map will

show that such lakes were among the most natural features at that time. The northward slope of the surface varies but little. Were those conditions again to recur, many northward slopes would again carry lakes. A valuable heritage has come to the state. Acting as great settling basins, these lakes held from further transport the fine silt that yields rich soils and laid it in broad plains of so sluggish drainage that waters are made to do their full duty before finally reaching the sea. Rich cornfields and hay meadows are developed on these lake-made plains, and upon the bottom of glacial Lake Agassiz has appeared the greatest wheat-garden of the world.

CHAPTER XXIV.

LAKE AGASSIZ.

The narrator of the history of lake Agassiz—Boundaries of lake Agassiz—The growth of lake Agassiz—The decline—The character of its bottom—The beaches and deltas incident to the southward drainage—Beaches with northward outflow—Variations in level—Controlling conditions of growth, maintenance and decline—Duration of lake Agassiz—Present aspects of its history.

Lake Agassiz was the grandest of glacial lakes. Pre-eminent in its class because of its vast size, its attractive history and the economic results which follow its remarkable though ephemeral existence, lake Agassiz is known wherever glacial geology is studied. Its situation upon the superb plain which is the central physiographic feature of the North American continent made those investigations possible which have developed our knowledge of the life history of a great lake long since disappeared. To the enthusiasm and keen scientific insight of Warren Upham we owe a narrative told with a fidelity that enables readers to see lake Agassiz in the stages of its growth, in the magnificent expanse of water and diversifying islands at its culmination and in the unsteady steps taken over many an abandoned shore-line as it settled into its dotage and became translated into the prairies

and water-surfaces which are so well known at the present time.

In earlier chapters we have read of the Ice age. It was during the closing stage of this period that lake Agassiz existed. A long, shallow valley lay between central Minnesota, where surfaces of ancient rocks stood 1300 feet above the sea in Stearns, Todd, Morrison, and Cass counties, and the steadily ascending surfaces of the great plain of North and South Dakota. This valley was shallowest at lake Traverse: deepening steadily northward its bottom reached down to the sea at the shores of Hudson bay. It is still a prominent geographic feature of the northwest. The valley like the hills on either side was covered thousands of feet deep with a great glacier. The advancing warmth of hundreds of seasons melted the ice. The water from the Minnesota hills flowed off rapidly, but all that in the valley to the westward below the level of Lake Traverse was dammed at Browns Valley. So far as we know this was the beginning of lake Traverse itself. As the great glacier melted away, a lake formed with its lower end at Browns Valley and its northern border an ice-wall; as this wall shrunk further back, the lake became larger. The end of its growing came when the northern ice-shore stood so far to the north that surging streams turned northwards and found the sea at the level of Hudson bay.

Boundaries of Lake Agassiz. The northern shoreline to lake Agassiz was the ice-wall. This was in retreat and thus continuously changing its position. The lake did not drain away until the neighborhood of Hudson bay was reached. To the west the lake spread to the somewhat abrupt uplift of land called the Manitoba escarpment and, to the south

to the very edge of the Coteau des Prairies. It reached the head of lake Traverse whence it poured its water through Big Stone lake and down the valley now

Fig. 111. Glacial lake Agassiz at its highest stage of water. In its northern half the boundary is partly approximate. Several other lakes formed in a similar manner are seen.
After Warren Upham.

occupied by the Minnesota, then by the river Warren.

To the east its border was in Traverse county near

the contour line of 1050 feet. The shore stretched northwards from this county in a nearly north and south line to Maple lake. Swinging eastward around this long, narrow lake, the well-defined beach line which marks lake Agassiz's highest stage still continuing eastward passed to the southward of Red lake entirely across Itasca county but in a very irregular course. A southeasterly stretching arm reached into township 62:25. Rainy lake and several existing water surfaces along the International boundary further east than Rainy lake were within the area of Agassiz. Around these lakes, where the highest beach lines have been measured, they stand 1230 to 1250 feet above the sea. Why this highest beach, which is only 1050 feet high at lake Traverse, becomes 1250 feet where it crosses the International boundary east of Rainy lake will be discussed further on.

The Growth of Lake Agassiz. Lake Agassiz had its days of small beginnings. Referring to the list of moraines in chapter IX, the ice retreat of the Red River glacier had reached the line of the Dovre moraine before the rim of the lake basin was passed and water began to stand. As the ice wall moved northward through the increasing warmth of closing glacial time, the height of the rim's lowest point remaining stationary, the water surface expanded northwards. Because the land was low, water surfaces instead of land areas continually stretched out. The ice intermittently moved northward across the land through successive Dovre, Fergus Falls, Leaf Hills, Itasca, Mesabi, and Vermilion morainic decades and doubtless for a much longer time. While the retreat continued through Manitoba, the lake continued to assort and distribute with its waves the ice-brought material.

The Decline. As the valley of this great lake area is studied it is seen that its waning and final disappearance were not accomplished in a day. There were repeated halts in the movements of degradation. These were long enough to leave imprints of re-constructive processes to a marked degree. During this time of waning the outlet must have been northeastward. How long the time in years, during which this process of obliteration went forward, is not known but it never ceased until the level of lake Winnipeg was reached.

The Character of its Bottom. Everyone who describes a glacier tells of the bowlders and finer material upon and within it, and of the turbid waters that flow from it. It can easily be seen that the waters of lake Agassiz carried out and settled enormous quantities of silt after the first coarser material was assorted and sunk. As in all lakes, this process prepared a bottom of fine mineral mud which afforded excellent ground for the adventurous plants settling anew the abandoned lake bed. Mingled with their remains, this mud has at length formed one of the richest soils the temperate zones afford.

It must not be understood that all this great lake bottom is of one quality: great diversity exists. Around the borders of the great lake lie many rock species which furnished the material from which soils were made. So effective has been the work of soil making that not one fiftieth of the surface is too poor to be worked with profit by the farmer. The peculiar soil quality developed has made the finest wheat region of the world. It may also be stated that hundreds of acres are underlain by beds of clay of excellent quality for the manufacturer. This assures building material for the future generations.

The Beaches and Deltas Incident to the Southward Drainage. The story of a lake is graven in the records made during its maximum and decline. With the piling up and overflowing of waters all steps are obliterated and all stages washed out. The period of culmination was doubtless long, much longer than

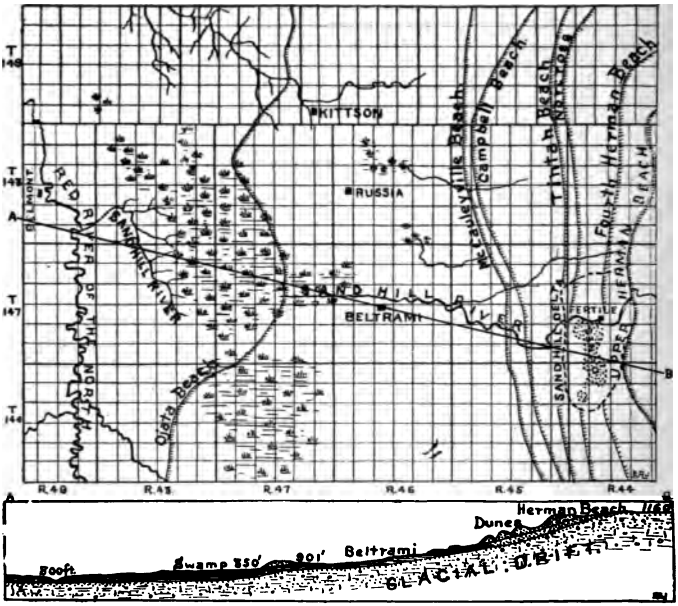

Fig. 112. A portion of the present valley of the Red river. The Sand Hill river flowing down from the hills, disappears in a large swamp; along the west side of this swamp a series of creeks collect the water, and reform the Sand Hill which continues to the Red river. Drainage and cultivation are changing the swamp into fertile farms. A profile of the district is shown along the line A B.

that of decline; yet it is only of the latter that the records speak. As lake Agassiz existed when at its

maximum, its outlet was 1050 feet above the sea. A well-formed beach extended northwards for 140 miles, in an almost continuous line of gravels and sands, to Maple lake. Here lie curious evidences of oscillations in a succession of these beaches four in number, near together and differing only a few feet in altitude. From this point eastward is a somewhat tortuous line to the International boundary. This it crosses at 1230 feet, or 180 feet higher than the outlet at Browns Valley. This remarkable shore line, traced across Minnesota from South Dakota to Ontario, is called the Herman beach from the town near which it appears in typical form. It represents work of the highest waters accumulated in the lake Agassiz basin.

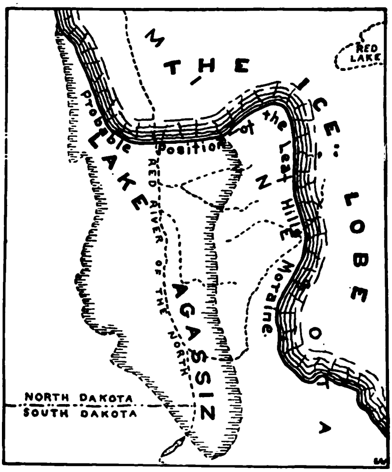

Fig. 113. Sketch of one of the early stages of lake Agassiz. The glacier was forming the Leaf Hills moraine. This and figure 111 are taken from Monograph XXV, U. S. Geol. Survey. The glacial lake Agassiz, by Warren Upham.

As time went on the waters wore away the outlet and the lake surface steadily sank. It would appear that this wearing took place somewhat erratically since the successive beach lines stretching northward sink away from each other in varying steps. Seventeen is the number counted by Mr. Upham as marking the flow towards the river Warren.

Beaches with Northward Outflow. In the course of time the waning lake had sunk to a level below the outlet at Browns Valley. This was caused by the opening of a water-course far to the northeast. Before such event the floods of water pouring southward had cut the outlet down many feet. Present surfaces show a cutting along the slopes beside lake Traverse from 1030 feet, the height of the beach gravels at Herman, down to 970 feet. The cutting of a river channel can be seen in many districts at the present day. Note what the Mississippi river has done in wearing rocks of quite a different type from those lying between Big Stone lake and lake Traverse.

Thus the land surfaces to the northeast became bared and the drainage was diverted from the Gulf of Mexico to the Gulf of Saint Lawrence and Hudson bay. Subsidence continued. Halt after halt in the sinking of the waters took place, Yet the draining of the great lake went on. Fourteen stages are shown by well-defined beaches belonging to this time of northeastern outflow, until the final respite from sinking formed the outline of lake Winnipeg.

Variations in Level. From what we know of shore lines around existing lakes we feel positive that the waters of lake Agassiz stood as level as the sea. Consequently the beaches formed by the waves were at one height in every place from north to south. But now there is considerable difference. The Herman beach, the highest of them all because formed at the maximum of the lake's expanse, is 1030 feet high at lake Traverse and 1167 feet at Maple lake, an increase in elevation of 137 feet. The air line distance is 140 miles. The change in elevation of nearly one foot per mile is remarkable, As the beach is followed eastward be-

yond Rainy lake it becomes 1230 feet high, 260 feet above lake Traverse.

The only satisfactory way of explaining this is to assume that the ground has settled to that extent around lake Traverse or has been uplifted at Maple lake and northward. For reasons not necessary to discuss here, Mr. Upham holds that the movement was upward towards the north, that while the ice was melting and the load on the earth was being lightened by the draining off of these vast waters, the earth's crust moved upward and that this movement not only continued long after the ice and waters were gone but that in the region of the Hudson bay it is even now in progress. But the rate is extremely slow; a few inches in a hundred years is not enough to produce any marked change in the geographical enviroment of the Red River valley in many centuries.

Controlling Conditions of Growth, Maintenance and Decline. Bringing in review the conditions of formation and deformation hurriedly sketched, the history of lake Agassiz can be outlined as follows: In the last period of glacial retreat from the western United States there was passed over a tract of ground, lying partly within the present state of Minnesota, the slope of which was northwards. As the ice melted and the front of a great glacier slowly, and somewhat interruptedly, retreated towards the north, the waters formed a lake. As the retreat of the ice continued, yet with some occasional re-advances, the waters in this lake assorted and spread out the rock debris which, where land occurred, was piled up as a succession of moraines. The lake grew larger, and became deeper until in the region near the northern boundary of Minnes over 400 feet. Truly a very

shallow lake for one so vast, since its total area was not less than 110,000 square miles, greater than all the Great lakes of today.

Within its very nature as a lake lay the conditions of degradation; not alone did its surface sink, through the deepening of its outlet past Browns Valley, but earth-warping turned the waters towards new outlets to the north and east. Successive beach lines prove successive halts in the final drainage, until conditions prevailed not very different in their physical aspects from those of today.

Duration of lake Agassiz. To everyone the question occurs, How long did lake Agassiz last? How many years was it from the first pool in the trough of lake Traverse till approximately the present boundaries of lake Winnipeg were attained? At first thought an answer seems impossible. But if the same measuring rod be used that is applied in other problems very reasonable results may be obtained. That is the rod of accomplishment: What did lake Agassiz accomplish?

In the first place the thickness of lake sediments may be noted. The lakes once occupying the basins of Utah and Nevada, called Bonneville and Lahontan, deposited fine marly clays and fine sands to the depth in each basin of more than one hundred feet. Lake Agassiz deposited no such bed. Indeed, over much of its extent the glacial drift is covered by a layer of lake sediment at its maximum only a few feet in thickness and often there is none at all. While the period of existence of lakes Bonneville and Lahontan is not accurately known, it is known that that of lake Agassiz was much shorter.

When compared with post-glacial lakes the result is

more satisfactory. Mr. Upham selects lake Michigan because its shores are alike in direction and general topographic features to those of the southern end of lake Agassiz. The character of the shore-line deposits and slope of the lake bottom are the same. The shores of lake Michigan have suffered an amount of wave erosion so much greater than did those of lake Agassiz that the proportion is ten to one. The beach deposits of lake Michigan are much greater and the sand dunes are correspondingly larger than those around the borders of lake Agassiz and on the delta sands.

Further, the beach ridges around lake Winnipeg are much greater than those of their great predecessor, lake Agassiz, thereby indicating longer time; because this smaller lake cannot have more powerful waves than had the larger. From such data Mr. Upham reasons that lake Agassiz could not have been in existence more than one thousand years.

Present aspects of its history. A fertile soil is not made in a day. Such has been the story of the Red River wheat fields. The fine silt, consisting of varied mineral material segregated by the ice, washed out, assorted and settled in the great lake basin, has been slowly and steadily commingling with organic matter, until to a depth of many inches a rich loam has been produced. Before the advent of the wheat farmer these lake plains afforded rich pasturage for countless buffaloes. Today conditions are brought under control. Nearly every acre is made arable, and the home of a prosperous community is established.

CHAPTER XXV.

THE STORY OF THE GREAT LAKES.

When the Great Lakes first appeared—Changes in level—Some earlier marginal lakes—Their culmination—Beginnings—Lake Nemadji—The Boulevard Beach—Southward drainage—Lake Duluth—Lake Algonquin—Unequal uplift—Problems of time.

The question is often asked: Did any great lakes exist before glacial time? The story of North America in the region of the Great lakes during the time immediately pre-glacial is well-nigh obliterated. The successive ice-invasions planed off the rock surfaces and removed most of the traces of earlier conditions. With the deep earth trenches in which these lakes lie,—lake Superior, for instance, reaching 450 feet below the ocean level,—comes strong confirmation to the minds of many that this lake is not the "creature of a day'; it represents at least a week of earth's history. The abyssmal depth also indicates that at some earlier time the land was higher than now, because valleys are not eroded by the sea. The Great lakes, as they are known today, came into existence with the close of the Glacial period. Some hold that they mark the sites of old river valleys greatly enlarged by ice erosion, and many most convincing reasons for this view are set forth. Earlier conditions, whatever they might

have been, are so modified that records must be dated anew.

Changes in Level. As long ago as 1850, the sink- of the west end of lake Superior was observed. The evidence lay in the filling of the mouths of the streams and the conversion of flood plains along their lower courses into swamps. It is established that within 100 years the lower rapids of the Saint Louis river at Fond du Lac have retreated up stream more than a mile. this retreat points to the sinking of the river bottom at least six or eight feet during this time.

Fig. 114. View from Duluth across the Saint Louis river valley. On the right hand horizon slope are to be seen the abandoned beach terraces of successive glacial lakes from Nemadji to Algonquin.
Photograph by F. L. Barker.

The direction of land movement has not always been downward. Within quite recent times it was upward. The story of such upward movement is read in the shore lines of vanished lakes whose waves played with pebbles now lying hundreds of feet above existing water levels. Such shore lines are seen all along

the Minnesota coast of lake Superior; they are noted around Carlton and Thomson, at Duluth and many other places before Pigeon river is reached. Lawson has discovered and described more than a dozen abandoned beaches, within this state. At Poplar river eight separate beaches one above the other, are distinctly seen; at Grand Marais, eight also, and not all of them are the same as those seen at Poplar river.

Some Earlier Marginal Lakes. While the great ice-sheet was slowly and with many oscillations making its retreat, the northward slope of the surface, strikingly shown in the altitude of the Nemadji and lower Saint Louis river valleys at the present time, made possible a series of lakes along its margin. These marginal lakes, we now know, extended in a magnificent series from Minnesota to New York. Lake Duluth was one; in eastern Wisconsin was another. The head of lake Michigan formed Chicago lake. The Bay of Saginaw was the site of another. Lake Erie, with the Maumee river as the axis of depression, stretched southwestward into Indiana and drained through the Wabash river into the Ohio. Lake Ontario emptied its waters through the Mohawk valley into New York bay. These lakes, and there were others with them, with ice-walled, northerly shores existed long before Niagara river began to flow and that great cataract to saw into the edges of the rocks.

Their Culmination. While the ice-sheet was retreating, the glacial lakes grew until they united with each other into a single sheet of water at least 150,000 square miles in extent, or more than twice the area of Huron, Michigan and Superior combined. This enormous lake occupied the surface now filled by these three lakes named, with much additional land along their

margins. It drained eastward through the valley now used by the Canadian Pacific railway from Sault Ste. Marie along the north shore of Georgian bay, past lake Nipissing, into the Ottawa valley. In time, probably through an uplift of land in the lake Nipisssing-Georgian bay region, the outlet of this great inland sea was pushed southward. The waters poured into lake Erie and rushed eastward towards the sea, the falls of Niagara, at the same time, assuming their present magnificent proportions.

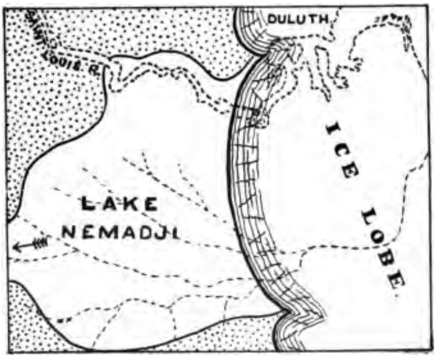

Fig. 115. Lake Nemadji when its outlet was near Moose lake. Boundaries approximately parallel with, but lower than the contour of 1100 feet.

Beginnings. When the lake Superior ice-lobe reached southwestward as far as Carlton and Cloquet the Saint Louis river probably flowed southward into the Mississippi or Saint Croix. As the ice retreated over the northeastward sloping surface, a lake was formed. As the ice uncovered the ground along the south side of the great eastward stretching basin, successively lower places in the rim were uncovered and repeated outlets were found each forming its beach, Many of these beaches are still to be seen. One of these outlets and abandoned river valleys extends from Carlton to Mahtowa. It is now occupied by Otter creek, the Northern Pacific railway and many good

farms. Another depression from the northeastward towards Barnum was an outlet long enough to make very strong beach lines across the glacial drift and underlying rocks. Still another outlet is seen southeast of Barnum and about six miles south of the preceding one.

Lake Nemadji. The outlet for the waters from the melting ice stood for a long time at this level, changing in height only as the stream cut into the loose morainic and modified material over which it flowed. Large quantities of sand and mud were brought in. The lake bottom was silted up many feet. Today this material forms, with that deposited during later stages, one of the most valuable deposits of brick clay yet

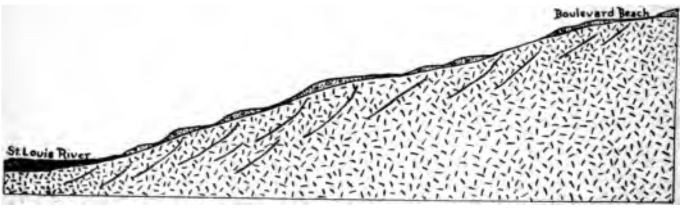

Fig. 116. Profile showing the successive beach terraces in the western part of Duluth. Sketched from the photograph reproduced in figure 114.

discovered and worked in the state. The Wrenshall and Clear Creek brick yards are upon it.

The Boulevard Beach. Upon the hills in the city of Duluth, about 475 feet above the present waters of lake Superior, an especially prominent beach line is seen; both above and below it are several others. Upon this particular beach has been built a boulevard following its windings along the hillsides for several miles. This Duluth boulevard is the most strikingly beautiful drive in the state. High above business-built Duluth and West Superior, the harbor and the lake, the view from it is most magnificently grand. Boulevard beach

and its associates both higher and lower have been traced many miles eastward, fringing the hills along the north shore, and westward towards Thomson and Carlton. They mark the northern border of one series of the most westerly of this chain of marginal Glacial lakes which stretched from Duluth as far eastward as the foot of lake Ontario. The story of this beach in its essentials is the story of them all.

Southward Drainage. In the ice-retreat from the slope of the lower Saint Louis and Nemadji river valleys, an increasing sheet of water was formed. Its outlet was southwards. The volume of water gathered from its melting northeast shore-wall, and its northwest drainage basin was thus added to the Mississippi river through the Saint Croix. The stream flowed at first through the valley now occupied by Otter creek and the Moose river. Its bed was 1150 feet above the sea on the divide between the two streams. This amount of water added to the Saint Croix made that stream a more powerful agent of erosion and land sculpturing than it now is. High bluffs and scenic dalles along its lower course stand today in beautiful evidence of its earlier work.

As the weather became milder the water surface became larger. Its northwest shore was high and rocky; the south shore lengthened until the present Brulé river of Wisconsin was reached. This stream and the Saint Croix now have their source in one swamp 1070 feet above the sea level.

Lake Duluth. The body of water at that stage is called lake Duluth. To reach its outlet through the valley now occupied by the rivers Brulé and Saint Croix and the swamp in which they rise, the water surface had sunk through two or more stages from 1150

feet to 104 ~~1070~~ feet. The beaches all around its margin were shaped anew 80, 65 and 40 feet below the beach formed when the outlet was through Otter creek valley. Thus there were several stages of sinking while the outlet was making its way eastward toward that great swamp valley across the plateau-like area of northwestern Wisconsin. The abandoned beaches at Duluth and down the north shore give weight to this view.

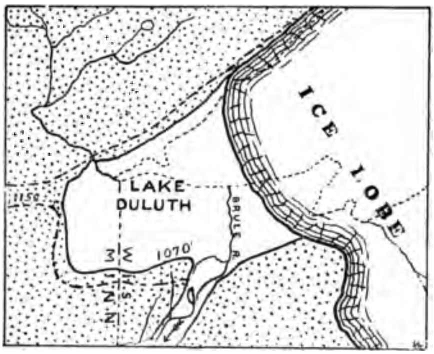

Fig. 117. Lake Duluth. The level of the water at this stage was about 1070 feet. At 1150 feet was probably the outlet of a lake existing before lake Nemadji.

Lake Algonquin. As the ice continued to retreat, other more eastward outlets were doubtless formed through which the waters poured southward until the retreating ice-wall rested upon the land near Sault Ste. Marie. Then lake Duluth became one with lakes Chicago and Saginaw, which sheets, expanding, stretched back from Chicago and the Saginaw valley towards the same focal point.

Thus lake Algonquin was created, to exist until tilting of the land upwards had lifted the region between lake Huron and the Ottawa valley so high that the waters flowed southward and found their way through lake Erie and Niagara river into lake Ontario, and thence into the gulf of Saint Lawrence.

Unequal Uplift. Since the date in the series of events which marked the disappearance of the ice from the Great Lakes region and the sinking of the waters of the several lakes below the lowest passes of the great divide separating the Saint Lawrence from the Mississippi basin, the story of the lakes has been a varied one. Beach lines are appealed to. They show long belts of gravel and sand that were horizontal

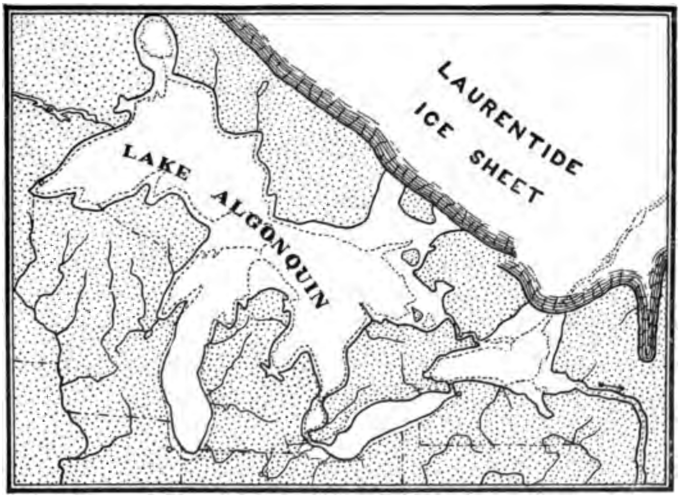

Fig. 118. Lake Algonquin at one of its stages. Adapted from F. B. Taylor

when first accumulated. They are not horizontal now. The boulevard beach of Duluth varies many feet in its altitude above present lake Superior as it is followed from its western terminus down the north shore. It is higher the farther eastward from Duluth it is traced. This proves that the northeastern part of lake Superior has been elevated relatively to the southwestern. Its waters are pouring southwestward. In other words

Duluth is gradually sinking to the water-level of the lake. It is clearly seen that Saint Louis bay and river as far west as Fond du Lac are being "drowned."

This elevation of the land towards the northeast has a profound effect upon the drainage. It blocks it so that another outlet must be found for lake Algonquin; the rising northern land causes the waters to rush southward and break over the divide between lakes Huron and Erie. Niagara becomes the cataract we see today, and the northern river bed past North bay now carries the roadbed of a great trans-continental railway.

Problems of Time. But no one can tell the length of time occupied in sinking lake Superior from its highest to its lowest level. Some geographers consider it as long; others as short. Each one of the terraces or beaehes along the Minnesota coast, and nineteen of them have been counted, marks a stage in the sinking. Whether each marks a separate outlet of lake Superior no one can tell; probably it does not. It is possible that some of them indicate differential movements, that is, movements which occurred in one part of the lake basin, but did not extend throughout its entire area. That the length of time for this sinking must have been considerable is clear to anyone who reflects upon the time necessary to form a beach in any lake with which he is familiar. That the number of years can be counted in thousands seems a reasonable estimate from the work achieved.

Again, the time that has passed since the outlet settled into the Niagara route is long. The facilities for calculating it are admirable. Some of the keenest minds of America are at work upon this problem. Progress has been made. The epoch is stated now in thousands

of years. Yet it must not be forgotten that the profound events of earth history involve time so long that it cannot be grasped by human thought! To earth events the measure-unit of human history, the year, cannot be applied. We use only words.

CHAPTER XXVI.

THE ECONOMICS OF LAKES.

Lakes as storehouses of heat—As sources of food—Transportation—As reservoirs—As pleasure resorts—Agricultural possibilities—For further reading.

Lakes are vast storehouses of heat. We scarcely comprehend the enormous possibilities in this territory of the far reaching influences that lakes bring to bear on climatic conditions. Figures mean but little when they represent numbers so large that we cannot grasp the quantity. Still, let us figure. The Minnesota lakes comprise an area of 5,638 square miles, and may be estimated at 10 feet in average depth. There are thus within the state 10.68 cubic miles of lake water. Each cubic foot of this water has a temperature in winter of 32°; in summer the average becomes about 75°, or 43° above the freezing point. Each cubic foot will therefore contain 1,250,000 foot-pounds of heat, that is, heat enough to raise a block weighing 1,250,000 pounds one foot from the earth, since a foot-pound is a mechanical unit and means the force required to raise one pound one foot high. The entire lake water of the state thus converted contains the enormous power of 1,962,639,360,000,000,000 foot-pounds! In other words, there is heat

Fig. 119. Lake Alice in the heart of Fergus Falls.
Photograph by E. E. Adams.

enough stored up in the lakes of Minnesota each summer and given off during the cooling autumn to raise a block of granite as large as a township and 100 feet in thickness to a height 800 miles above the sea. Yet all this stored-up heat, compared with that stored in the earth at the same time, is as a mere toy to a Corliss engine.

Minnesota climate is subject to sudden changes. Still, the utility of the heat stored in the lakes is recognized. Farmers like to put in their crops upon the south side of a lake; they place their gardens thus whenever they can. Grape growers at lake Minnetonka plant their vineyards at Excelsior instead of Minnetonka Beach. Frosts come earlier on the north side of the lake than on the south side; some years there is a difference of two weeks.

As a Source of Food. Every boy who frequents

lake shores doubtless understands the secret of frog catching. The value of the frog as an article of food is underrated save by the garter snake and the crow. The principal product of lakes is their fish. Hundreds of thousands of dollars will scarcely measure the market value of this product obtained from the lakes of the state. The fun of fishing leads thousands of people to the lakes and streams; such fishermen scarcely think of computing the money value of their catch. Yet around the larger lakes is quite a population who live almost entirely as fishermen. Such large lakes as Minnetonka, White Bear, Mille Lacs, Pepin and a score of others, yield a constant supply. It is from the lakes

Fig. 120. The rocky north shore of lake Superior with a strong wind blowing off the lake. Near Grand Marais, an important fishing station.
Photograph by H. W. Gleason.

of the northern boundary and lake Superior that the largest product is obtained. From lake of the Woods the return amounts to tens of thousands of dollars; that

portion of the lake Superior supply fairly Minnesotan is much larger.

Transportation. Lakes have been recognized since prehistoric times as great thoroughfares of commerce. Those early peoples who made annual visits to the copper regions of lake Superior utilized lakes and rivers alike as their grand routes of travel. Their importance is recognized still. There are tracts in northern Minnesota that would yet be practically inaccessible were it not for the chain of lakes and stretches

Fig. 121. Minnesota Point. Projecting from the shore between lake Superior and the Saint Louis river, it forms one of the safest harbors in the world.
Photograph by F. L. Barker.

of connecting river upon which canoes, rowboats, and small steamers ply during the summer season.

As Reservoirs. Lakes must be brought into use
and more as great reservoirs where waters may
ounded for the manufacturer's power, devel-
electrical industries and for irrigating fields.
ndreds of square miles which can be used
hereby increasing the available horse-

power of the state by tens of thousands, and advancing in a material way its agricultural interests. The reservoirs about the sources of the Mississippi have already been discussed.

As Pleasure Resorts. People who delight in nature, and particularly residents of southern latitudes, find great pleasure in spending the warm months on the banks of Minnesota's beautiful lakes. It is delightful to bathe in their cool waters; there is refreshment even in the air that blows across their surface. Summer resorts throughout the state are constantly increasing. There are many lake residences from the cottage, crude and simple, to the villa as elaborate in its appointments as a palace. There is pleasure too, in possession. The farmer takes pleasure in his lake; his cattle enjoy the cool waters; and even the pleasure of a boatride, is enhanced when the feeling of ownership enters into the contemplation.

Fig. 122. A cosy little cottage beside a Minnesota lake. Such a summer home is within the reach of many.
Photograph by A. S. Williams.

Agricultural Possibilities. In their waning and final disappearance lakes yield their greatest returns toward the advancement of mankind. It is through the constant and systematic tilling of the soil that the greatest human possibilities are secured. An agricultural region is capable of dense population, and

where the soil is most fertile there is the most successful agriculture. The bottoms of extinct glacial lakes;

Fig. 123. A beautiful lakeside cottage at lake Minnetonka.
Photograph by A. S. Williams.

the filled up ox-bow lakes of alluvial plains; the dried-up lake surfaces of higher lands; these, agriculturally,

Fig. 124. A Minnetonka villa.
Photograph by A. S. Williams.

are the richest spots within the state. It is here that the farmer locates his choicest fields, and from these acres he expects and receives the largest returns in tons of produce. It has been well said that the greatest use of the existing Great lakes of North America will accrue when, filled up and converted into farms, their surfaces shall have become the homes of a large and thrifty popu-

Fig. 125. Grand Marais harbor and lighthouse. This is an excellent harbor of refuge for the north shore. The outer wall of the harbor is formed by a reef of volcanic rock which is connected by a gravel spit with the main land.
Photograph by C. J. Hibbard.

lation. Such a contingency lies in the future. Meanwhile, Minnesota farmers, with careful and wise judgment, continue to develop the acreage constantly accruing as lake after lake disappears, and put it to the highest and most successful use to which land is applied.

For Further Reading. In the descriptions of the eighty-two counties of the state are many paragraphs giving information about lakes. As especially profitable for reference reading the following are suggested, all excepting three from volumes I, II and IV of the Final Report of the Geological Survey:

Lakes: I, 130-132; II, 472-475 and 535-538; IV, 56-58.

Oxbow lakes: IV, 26, 27; **silted river lakes** (lake Pepin) II, 3-6 and 25, 26.

Chains of lakes: I, 479-485; IV, 84, 87-90.

Lake Agassiz: II, 517-527, 664-667. Monograph XXV, United States Geological Survey, is entitled, The Glacial Lake Agassiz, by Warren Upham.

Glacial lakes: I, 130-132, 407, 408, 461, 462; lake Nemadji IV, 3, 18-22 and 218-221. Bulletin Geological Society of America, vol. X, 109-128, Glacial Lakes of Minnesota, by N. H. Winchell.

Lake of the Woods: Minnesota Botanical Studies, vol. I, 949-1042. Observations on the Distribution of Plants along shore at Lake of the Woods, by Conway MacMillan.

Paragraphs discuss the geography of the region.

CHAPTER XXVII.

THE PRAIRIES.

Definition—Classification of prairies—The origin of prairies—Industries of the prairies—Retrospect—Prospect.

A prairie is a level or rolling tract of land covered with grass instead of trees. Its soil is generally rich. The prairies of the United States are, in their typical aspects, sharply defined from the plains, since they have sufficient rainfall to support abundant vegetation, and the plains have not. Yet the border between the two is not so easy to define. The prairies develop in the Mississippi basin and stretch westward and upward until they are lost in the vast stretches we call plains. The plains on the other hand extend eastward from the foothills of the Rocky Mountains and merge into the prairies of lower level and greater rainfall.

Classification of Prairies. In Minnesota, prairies are of somewhat different types. In the southern and southwestern portions of the state they are in places rolling, in other places level. They cannot easily be classified according to rock formations beneath; the glacial drift, which forms a universal covering over the underlying rocks, prevents such discrimination. These rolling-to-level prairies constitute the major part of Minnesota's prairie area.

A second type of prairies is the openings seen oc-

Plate V. The lettered lines across the state represent the northward limit of forest trees as follows:

A. Honey locust, *Gleditsia triacanthos* Linn.
B. Swamp white oak, *Quercus platanoides* (Lam) Sudw.
C. Common locust, *Robinia pseudacacia* Linn.
D. Shag-bark hickory, *Hicoria ovata* (Mill) Britton.
E. White oak, *Quercus alba* Linn.
F. Cork elm, *Ulmus racemosa* Thomas.
G. Kentucky Coffee tree, *Gymnocladus dioica* (Linn) Koch
H. Western crab-apple, *Malus Ioensis* (Wood) Britton.
I. Southern limit of pines, Northern limit of soft maple, box elder, wild plum, hackberry, slippery elm and cottonwood.
K. Black walnut, *Juglans nigra* Linn.

casionally within the timber area. Green Prairie in Morrison county is an illustration of such an opening. Upon one side is the Mississippi river; on the other side extends a fringe of forest. Many of these openings occur along the border line between the forests and prairies as is shown on the map.

A third type of Minnesota prairies is represented

Fig. 126. One of the prairie openings so frequent along the forest border. In the foreground is a group of elms; in the background are oaks. West of Minneapolis. *Photograph by A. S. Williams.*

by the great level lake bottoms of the state. The Red River valley is naturally thought of as the first illustration of these prairies. It stretches from lake Traverse northward in a continually broadening and singularly level area of remarkable fertility. These areas have

already been described where the characters of the glacial lakes of the state were discussed.

The Origin of Prairies. A score of different opinions have been published on the origin of prairies. One opinion is that prairies are closely related in their distribution to the distribution of a soil of peculiar fineness. Some time ago Professor Whitney maintained that prairie soils must be extremely

Fig. 127. A prairie scene in the Red River valley. Locality near Homes. The rolling ridge is the Campbell beach of lake Agassiz; the cooley in the foreground is cut by a stream flowing across the beach towards the west.
Photograph by C. J. Hibbard.

fine. To support this, he stated that whole counties in Iowa could be travelled without finding a single pebble, while the timber tracts farther north are tracts abounding in pebbles and boulders. Another claimed that prairies are due to continuous winds that sweep from

the west toward the east across the Mississippi valley. Another maintained that the distribution of rainfall first marked the boundary of the prairies, and subsequent incidental conditions of diverse character have maintained the line of division between plain and prairie, and prairie and forest. Others claim that sweeping fires have denuded vast areas of their forests, and growing grasses have prevented the trees from regaining the ground fires had compelled them to surrender. Professor Shaler has recently asserted that indirectly the American bison is the cause of the American prairie: that in prehistoric times the Indians of the southwest discovered in the bison an excellent food, and that hunting the bison was more exhilarating sport than ordinary river fishing, and far more profitable than hunting the carnivorous animals that lived in the forest and fed on the buffalo. The Indians soon observed that the bison thrived wherever the prairies afforded feeding ground. It did not take them long to learn that if the forests were removed the bison would range farther and farther from his southwestern home. Gradually, by a rude system of stock raising, the prehistoric inhabitants of this country extended the range of the bison, or, as this animal is more commonly called, the buffalo, into the heart of the continent. A persistent system of forest-firing accomplished this by pushing the grass-clad prairies northward into Manitoba and eastward well up the slopes of the Appalachians. When the white man crossed the mountains, this crude system of agriculture had been in operation sufficiently long to convert vast areas into smooth and perfectly developed prairies supporting a plant population that defied the effects of fire by means of its established habit of extending itself be-

neath the surface instead of above it, by underground rootstalks instead of broadly spreading branches.

Industries of Prairies. Prairies are the centers of a somewhat dense agricultural population. Incidentally, still denser communities grow up to supply the further needs of modern living. These manufacturing centers and distributing points are common throughout the prairie regions. The soil of prairies is so rich and so easily worked that it is one of the most desirable soils of the world. That of Minnesota is further

Fig. 128. A hay meadow on the prairies of Freeborn county. The sluggish stream tells of the springtime marsh and moist soil of the later season. *Photograph by P. D. McMillan.*

peculiar in being thoroughly diversified. The bringing to the state of boulders, pebbles, and grains from rocks of every northward-lying type has given it a wide range of chemical qualities. In any region of the state any crop the climate will allow can be raised.

Retrospect. The prairies have proved a remarkable incentive to progress throughout the west. In colonial days, years of time were required by every husbandman to clear of trees the land of the Atlantic

Fig. 129. A prairie scene in southwestern Minnesota. Trees will grow if only protected from prairie fires and the bush scythes of the farmers.
Photograph by C. J. Hibbard.

slope and make a farm. The immigrant to the prairie region finds his ground forestless and ready for the plow. Farm after farm has been taken up and brought under cultivation in rapid succession. Thousands of farms can be opened in the prairie portion of this state while hundreds are being opened in the forested region.

It is thus that the prairies have affected the movements of population. There are many conditions of the prairie favorable to the prosperity of its inhabitants. The facility with which crops are grown and products moved has stimu-

lated to an extraordinary degree many lines of commercial activity: railroads have been pushed forwards literally hundreds of miles beyond the western border of cultivated farms; manufactures have sprung up; scores of industries related to the distribution of the products of industry have been established.

Prospect. Human activities are bringing a change. Traversing southern Minnesota, the long treeless stretches that once met the eye of the traveler are now broken by villages, farms and groves of trees. Proper foresight will cause farmers to let the trees grow that are rapidly springing up everywhere since prairie fires have been stopped. It will be only a short time before a necessary forest growth will have been developed to supply all needs of the farmer for wood and timber. The tremendous commercial movement made possible through the absence of heavy forests will continue in increasing ratio. The streams will be utilized until every cubic foot of water, before it finally moves on toward the sea, will have done its service to the farmer, the manufacturer, or the city home-possessor.

CHAPTER XXVIII.

THE FORESTS.

General considerations—Minnesota woods—Are forests advancing?—Historic notes—Origin of forests—Forest fires—Economics of forests.

A forest is a tract of land covered with a natural growth of trees and underbrush. Ordinarily two kinds of trees are recognized: the ordinary trees of the farm and village, cultivated for fruit or hedge or shade; and the forest trees, growing wild, and used for many purposes. As seen on the map of forest and prairie, 52,000 square miles lie in the forest belt of North America. Minnesota is one of the largest producing states in lumber records. The United States produces more lumber than any other country in the world, and uses far more. Lumber is consumed in the building of homes and in almost every line of business. Enormous consumption and the waste entailed in the clearing up of thousands of farms have for hundreds of years been making irreparable inroads upon the forests. upply of wood and lumber drawn upon has been diminishing. The resources of the country egarded as so nearly inexhaustible that no- been exercised to replenish consump- ssible needs, men cannot look for-

ward for the length of half a century; and that is the average time it takes to mature a forest. It is more than most men do to span a year with frugal prevision.

Minnesota Woods. The woods of Minnesota are hard and soft. The forests are either hardwood forests, softwood forests, or forests where hard wood and soft wood grow together. The soft woods are chiefly conifers. The magnificent species is the white pine. This tree a few years ago occupied extensive areas in the northern and central portions of the state within the drainage basins of the Saint Croix, Mississippi, Saint

Fig. 130. A farm scene in winter within the forest area. Trees once grew where now are highly productive fields.
Photograph by A. S. Williams.

Lawrence and Rainy rivers. It is such a favorite for ordinary kinds of lumber that the supply is diminishing with alarming rapidity. Conservative estimates in 1870 gave hundreds of billions of feet of standing pine in Minnesota; now the supply is calculated in thousands of millions. In a few years extensive commercial enterprises based upon the exploitation and manufacture of the white pine will be incidents of the past.

The hard woods which stand in that extensive southwesterly-stretching tract called the Big woods

are more slowly cut away. As ground is needed for farms or the wood supply is called for by cities, this timber belt is drawn upon with increasing rapidity. The manufacture of paper is reducing the amount of basswood and spruce, while the hundreds of demands of civilized life are taking trees of every species fit for the manufacturer's use.

Are Forests Advancing? In spite of this rapid consumption, trees are advancing. Prairies are being for-

Fig. 131. A mixed pine forest in central Minnesota.
Photograph by A. S. Williams.

ested wherever opportunity is offered, In the south west part of the state hundreds of farms, entered under the Tree Culture Act of Congress, have beautiful groves. Timber belts along lukes and streams are expanding. Everywhere opportunity offers, the forested borders of the prairies push back the grass and increase the area of trees.

Historic Notes. The history of the state shows that several concessions of land by the Indians to the whites involved forested tracts. Treaties of cession involved indirectly the cessation of hostilities between warring tribes. Instance two: the treaty under which the Chippewas granted to the whites the great lumber region of the Saint Croix valley, and that under which the Sioux ceded all of their land east of the Mississippi

Fig. 132. A mixed pine forest near Hibbing. The ground is a morainic ridge abounding in boulders and is designated by Gen. C. C. Andrews "non-agricultural land."
Photograph by A. S. Williams.

river, separated these two bitterly hostile tribes by more than one hundred miles. With the surrender of these lands came practically the close of Indian wars, since it was illegal for warring bands to cross neutral territory. Hence the lumberman in entering this region was the cause of stopping bloodshed and the

promoter of peaceable relations between tribes that had for generations regarded each other with that bitter hatred proverbial of the American Indian.

Origin of Forests. Forests are due to two causes. The first is partly topographic but chiefly climatic. Differences of soils depend upon differences in the material out of which they are made, but also upon elevation above the sea, temperature and humidity of the air, and other physical conditions. The second group of

Fig. 133. A typical lumber manufacturing plant. The establishment of the Sauntry-Cain company at Sandy Lake.
Photograph by A. Carlson.

causes is historic. Minnesota is, physiographically, new, and the trees which are here have entered the region in a certain historic order. They have come from the south from the north, and from the east and west. As seeds gain foothold, species develop, and the favorable or unfavorable character of the soil conditions determines the dominancy of the one or other type of trees. This is seen notably in the capture by the burr oak of the sand dunes of Anoka county and

surrounding localities; and in the occupancy of the morainic gravel belts by the several species of the pine in the central and northern portions of the state. In this last case we have a fine illustration of the distribution of plants which can live on a comparatively small amount of soil moisture.

Forest Fires. These disastrous visitations are becoming less in number and destructiveness. Once the

Fig. 134. The vigorous forest growth of the Mississippi bottom lands. Anchorage of zoological station boat Megalops near Brownsville.
Photograph by H. F. Nachtrieb.

sentiment was in vogue that fires were advantageous. Now all agree that they must be controlled. The great lumber tracts are becoming smaller. Farms interrupt the continuity of growing trees, and roads afford breaks against running fires. Close watch is kept during the summer to guard against setting fires and to check their ravages if started. State fire ward-

ens are educating the people to a knowledge of the losses which result from forest fires. It is not only that trees are killed and therein a source of wealth destroyed, but soil is burned out and nothing but barren tracts are left after the scourge.

Fig. 135. An elm grove in the Winnebago valley
Photograph by C. J. Hibbard.

Fires seldom destroy hardwood forests, as the foliage does not spread the flames. It is among conifers that fires speed, where large quantities of gum and

resin, and often inches thick of fallen resinous twigs add fuel to the flames.

Fig. 136. A grove of red pine, Minnesota Point. The favorite summer resort of Duluth.
Photograph by A. S. Williams.

Economics of Forests. Arguments need not be offered. Here may be made only a statement of a few points where trees touch the conserving side of life. They afford shade and comfort for man and beast; they protect the ground from parching; they guard the land surface against erosion. Trees furnish wood for domestic purposes. They constitute the universal building material for barbarian and civilized peoples alike. They are still used for ship building; they afford material for hundreds of manufactures, coarse and refined. For packing and wrapping, boards are the most convenient of all substances. In the making of paper, wood fibre is the best. Finally, trees are essential in the cultivation of the love of the beautiful and the appreciation of every aesthetic sentiment. Boulevards are not beautiful without vistas of trees; lawns and parks are incomplete without them; school grounds lack an essential element of beauty if the pupils fail to plant them with trees. Lake shore, river bank, hillside, and prairie all would seem bare and monotonous without this essential of landscape beauty.

CHAPTER XXIX.

HILLS.

Definition—Kinds of hills; bluffs, morainic hills—Significance of hills—Economics of hills.

A hill is an elevation of compact or loose rock rising conspicuously above the surrounding ground. Hills may be low in altitude, or strikingly elevated above the general surface. Hence the word hill is local rather than precise, and loose rather than scientific. There are many forms of hills to be noted within the state and westward as one journeys toward the Rocky Mountains. The moraines of glacial origin constitute the most conspicuous types of hills to be found in the state. In the Mississippi, Saint Croix and Minnesota river valleys a peculiar type of hill is everywhere seen. It is called the bluff.

Kinds of Hills. Bluffs are hills or cliffs with a broadly vertical face. Oftentimes they mark bold, projecting, and steep headlands. In this part of the United States bluffs are onesided affairs: they have one vertical face and on other sides extend away in a somewhat level upland, usually towards a river or lake valley. Bluffs are hills of erosion, due to the wasting effects of air and water upon rocks.

Passing still further westward, the structure called

Fig. 137. The bluffs along the Mississippi river near Kings cooley. The tributary streams have cut deep furrows in the eastern edge of the prairie.
Photograph by H. F. Nachtrieb.

the butte comes into view in the Dakotas. The butte is a hill which has assumed the form of a natural turret. It differs from the bluff in that it exposes a cliff-like wall on all sides instead of one or two. The butte is often seen in the west and represents a more advanced stage of erosion than the bluff—it may be called a sort of dissected bluff. The butte is composed of either volcanic or sedimentary rocks. The mesa with its volcanic cap, frequent in the southwest, does not occur in this state. The butte as a hill form occasionally rises in the bottoms of the Mississippi river.

Morainic hills are the most widely distributed. They appear almost everywhere that glacial till occurs. The slope of their sides varies greatly, as does their height above the ground level from which they rise. They are usually tillable to their very summits, yet sometimes so dry that cropping them is regarded as precarious farming. When

forested, longrooted trees will flourish and afford the farm a permanent wood supply from ground useless for other purposes.

A region of interest for its hills is the Leaf Hills. This tract in the western part of the state is typically morainic. It consists of a tumultuous succession of rounded, elliptical, and, more rarely, elongated elevations representing the contact of different advances of glacial ice with the debris which these masses left behind. The Leaf hills comprise the peaks of Otter Tail, Becker, and Douglas counties. Some of the highest attain an elevation of 1700 to 1800 feet above the sea. Lying at the feet of these hills are thousands of lakes of the typical morainic type.

In northeastern Minnesota hills are of an altogether different type. The Misquah hills, for instance, are the highest tracts in the state. They are high and almost naked masses of a rock named gabbro, a volcanic which after all the vicissitudes of its history stands in great dome-shaped uplifts of coarse-grained mediumly acid rocks. Around Duluth are many hills of volcanic rocks, some of which are masses of gabbro, and others of more or less dissected lava flows. The last are peculiarly susceptible to erosion, since the softer amygdaloidal portions are rapidly cut away. Dikes also, on account of their strong resistance to erosion, must be named as a factor in the making of hills.

Significance of Hills. As physiographic features, the significance of hills is quite as varied as the causes of their existence. Speaking broadly, they signify two things: effects of transportation, either to or from the state; and crustal movements which may be volcanic, or due to folding. As to the first, there must be

mentioned both the overwhelming of the state during the ice invasions, and the manifold effects of rivers and smaller streams working since the ice-retreat. As to the second, volcanic forces at work accumulate hills which sometimes extend into mountains, as around Duluth, or, eroded through the ages, now stand as the stumps of former hills or mountains, seen at various places in the Saint Croix valley, particularly in the Kettle river portion. Great folds in the earth's crust result in the uplifted slopes of the Mesabi iron range

Fig. 138. The butte type of bluff. This hill was once an island in the Mississippi river channel. The nature of the eroded rocks determines the form of hill.
Photograph by H. F. Nachtrieb.

and the folded schists around Granite Falls in the Minnesota valley.

Simple elevations due to folding are limited to a certain part of the state where millions of years ago rocks were bent into successive up-turning and down-turning flexures of rock masses. But since the time when the folding was accomplished, erosion has so planed off the surface that only now and then uplifts of sufficient dignity even to be called hills can be seen.

Bluffs occur along rivers Mississippi, Saint Croix and Minnesota. They are an interesting type of hills, often merging into the ordinary high land of the prairies, and even into the moraines of glacial origin. As the bluffs are ascended, still further heights may be scaled above the general level of the prairies. Along these heights erosion has determined outlines of hills. Where these can be followed for miles they develop into the ordinary heights of land, as the Coteau des Prairies and the Leaf Hills.

Hills share with lakes and forests the most conspicuous physiographic features of central Minnesota where is situated that geographic fiction, the Height of Land of the state. Here, instead of height of land, are a few lengthened elevations of morainic origin standing out above the general height of land as this is marked by swamps in the Upper Mississippi and southern Rainy Lake basins.

Economics of Hills. Hills are both an advantage, and a disadvantage to the farmer. As an advantage the elevation of the land above the general level conspires to comfort and helps the development of sentiment. Disadvantages are the tendency to a barren soil, dryness of soil and consequent exposure to drought, the exposure to winds, and the liability to early frosts.

In matters of village building, the hill aids effective draining, gives cheerful aspect to the home, and adds to the general aesthetic effect which the situation affords. In these respects hills have their advantages. Commercially, however, the hill is a disadvantage. It costs enormously to lift heavy loads to the tops of hills, and letting them down again is also costly. Hills must be cut down in the business portions of towns

The surface must be smoothed that large loads may be rolled easily across them. The material.thus removed is useful in filling marshy tracts and building somewhat higher than the datum plane of the district the avenues of travel and lines of transportation.

CHAPTER XXX.

MOUNTAINS.

Definition—The Sawteeth range—Isolated mountains of the Sawteeth range—Boundary peaks—The Giants range—The Shining mountains—Origin: volcanic activity; folding; fracture; the work of erosion—The uses of mountains.

A mountain is a lofty elevation of the land. It stands high above the surrounding country. Mountains may be isolated elevations, a series of high points, or practically a continuous ridge of the ground. Singularly enough, for a state forming the crest of the continent, and geologically one of the very oldest of the North American continent, this state has very few mountains of any cast or type.

The Sawteeth Range. The Sawteeth mountains along the Minnesota shore of lake Superior are about the only ones within the state. These consist of a succession of elevations sharply separated by valleys having long slopes upon one side and precipitous rock walls upon the other, thus giving the aspect of a series of saw teeth as one sees them from the lake. It is interesting to note in this connection that the Misquah hills form the highest land in Minnesota. They stand in the interior beyond the Sawteeth mountains. As one looks inland from lake Superior, or stands upon the peaks of the Sawteeth mountains and looks far to

the north, there in the distance, extending hundreds of feet higher towards the clouds, the Misquah hills are seen in a succession of great rounded knobs.

Isolated Mountains of the Sawteeth Range. Associated with the regular succession of peaks constituting the Sawteeth mountains are some isolated peaks. Mount Josephine is a huge unweathered dike, forming a bold promontory advancing into the lake more than 700 feet above its level. It is the east wall of Grand Portage bay. Carlton peak is a sentinel standing 927 feet above lake Superior as the west end of the Sawteeth range. It is a prominent land mark to the navigators of lake Superior.

Fig. 139. Barn bluff at Red Wing looking from the river towards the east end. This was once an island separated from the prairie to the south and west. It is now considerably quarried.
Photograph by H. F. Nachtrieb.

Boundary Peaks. On the boundary of Ontario in a bold headland looking northward over the Pigeon River valley, mount Northrop rises more than 1950 feet above the sea. The Twin peaks, standing a little farther west, are 2060 feet high. All three and many others around them are of massive volcanic rock.

Fig. 140. The Sawteeth mountains from Grand Marais harbor looking west. The peculiar serrate peaks reach from 500 to 700 feet above lake Superior. The most distant one, that standing almost behind the lighthouse, is Carlton peak. *Photograph by C. J. Hibbard.*

The Giants Range. Another ridge of no little interest is Giants range. This area of elevated land, made up of the gathered uplifts of the Misquah hills, carries this landscape feature westward and slightly southward many miles toward the central part of the state. This range of granites and schists makes the great rock bed against whose southern slopes the Mesabi Iron range with its rocks and iron ores stretches across northeastern Minnesota.

The Shining Mountains. The Shining mountains of southwestern Minnesota were an illusion in trapper days. This elevation, constituting the Coteau des Prairies, stretches across southwestern Minnesota from South Dakota into Iowa. The peculiar sheen which this sloping prairie surface afforded, as the sunshine and the hazy atmosphere enveloped it, gave the appearance which suggested the name by which this upland was known to the early explorers of the northwest.

Origin. But how are mountains formed? The answer is: they are formed in different ways. No two mountain chains are formed in precisely the same way. Nor has any one mountain been formed, in all the stages of its uplifting, by the even play of all the forces involved in its formation. At one period one force is predominant, at another a very different force accomplishes the greater work. In the first place, mountains are due to volcanic activity. They are made up of huge dikes, of lava flows, of piles of volcanic matter of other form. Sometimes they are due to folding. This has been the case in Minnesota in geologic ages past. Indeed, the great folds of rock that are shown by the slopes in the schists in the Minnesota river valley indicate that once upon a time in ages past huge mountains, formed by bending and pushing together of rock masses, occupied the ground. Erosion has performed its work so thoroughly that only the stumps of ancient land forms are to be seen. Hence the belief is not unreasonable that through Minnesota from northeast to southwest stretched at one time ranges of mountains whose degradation afforded the vast amounts of sand that make the sandstone beds of the Upper and Middle Mississippi valley.

Fig. 141. Carlton peak seen from the lake.
Photograph by A. H. Elftman.

Finally, mountains are formed by fracture. In the Great Basin are some of the most magnificent moun-

tains formed by fracture that the world can show. They are magnificent because of their newness. The Sawteeth mountains and high peaks of the International boundary are also formed by fracture, yet fractured so long ago that the evidence is much more obscure than in the west. To one sailing upon lake Superior who looks toward the northwest, the origin by fracture and

Fig. 142. The summit of Carlton peak, a huge mass of anorthosite coarsely crystalline feldspar. Its origin is volcanic. Height 1529 feet above the sea.
Photograph by C. J. Hibbard.

accompanying faulting of the Sawteeth mountains is plainly seen. The figure illustrates better than words, because more quickly done.

The Uses of Mountains. The uses of mountains divide naturally into two classes. In the first place, they determine climatic conditions, and their characters control largely the range of animal and plant life. It is well known that some plants grow on the tops of

Fig. 143. Mount Josephine. This peak is 1305 feet above the sea and is the most commanding elevation in the extreme northeastern corner of the state. The heights in the distance are in Ontario. At the base lies Wauswaugoning bay. A former beach line about 50 feet above the present water level can be traced around the bay to the foreground. The peculiar notch in the top of the peak on the left may mark a shore line of about the age of the Boulevard beach at Duluth. The forest habit of this portion of the state is seen. *Photograph by C. J. Hibbard.*

mountains and are never found around their bases; that some animals thrive in snow-clad regions but pant and die in warm surroundings. The direction of mountains produces its effect. A range standing north and south is a quite different factor in plant and animal migrations, as well as in wind currents and rains, from one standing east and west. So, too, there is a difference between mountains stretching up from the level of the sea, and those whose foothills are already thousands of feet above earth's datum plane.

Mountains are dominating factors in the activities of mankind. No more forcible illustration of this fact is seen than the struggles and sufferings of the pioneers while crossing the Appalachians and securing a foothold in the Mississippi valley. It was once said that all great communities were found less than 2,000 feet above the sea; but when large and prosperous commonwealths like Colorado and Montana are developed at twice that height, we see a very forcible illustration of the fact that the world was made for man, and not man for the world.

CHAPTER XXXI.

TRANSITIONS.

We come again to the solid ground on which the many processes thus far considered are going on. The ground consists of rocks. As varied as these objects are in all their physical and chemical properties, and in their origin itself, they all consist of units called minerals. Although the study of minerals as separate creations belongs to the science Mineralogy and the origin of the rocks with the many changes they undergo is a proper discussion for geologists, nevertheless a few paragraphs must here be given to such summary statements about minerals and rocks as shall point out their intimate relations to the geographic processes under examination.

The Glacial drift has been discussed in earlier chapters. This everywhere lies upon older rocks. Occasionally however these older rocks are in sight. Everywhere they are cracked, broken and worn. Water and weathering are continually doing their work. Both the drift and the underlying rocks are being broken down and changed into new minerals or carried away to exist under new surroundings. These for the most part are in the ocean.

Fig. 144. Pipestone creek and the Palisades. In the quartzite area of southwestern Minnesota. Water cuts away the hardest rock. The boulders in the foreground are rounded; the finer material is transported still further down the stream.

Photograph by O. H. Myrke.

Fig. 145. One of the many castellated dolomite bluffsalong the Mississippi river. Weathering cuts away the rock but the slope is so steep that but very little soil is retained; the waste supplies the bottom lands.
Photograph by H. F. Nachtrieb.

The mantle of rock waste which covers all rocks, thin and changing where running waters and waves wash away loosened particles, thick and stable where well protected, forms the soil. Within the soil are the mineral foods of plants. Here, too, are decaying vegetable matter and much moisture, which are also foods.

The soil is a most important factor of civilization. A knowledge of its character and capabilities enables one to control its products and command his own environment. The skillful farmer knows when to rotate his crops,

which means that he knows when his crop has exhausted some particular food from the soil. Another crop drawing upon the soil for other foods will allow physical and chemical changes to replenish the soil of its exhausted constituents and prepare it anew for service.

This is simply an illustration. In another place soils and their uses will be discussed, but the remaining chapters of this volume will treat of the minerals and rocks used by man and whose decay makes soils possible, furnishes the mantle of rock waste and supplies streams and lakes with their loads of boulders, sand and silt.

CHAPTER XXXII

MINERALS

Definitions—Some modes of occurrence—Gaseous, fluid and solid—Symmetry among minerals; Amorphous, Crystallized and Crystalline—Where minerals are found.

MINERALS ARE OBJECTS found in or upon the earth having certain characters which readily distinguish them from plants and animals. These are outward form, color, lustre, hardness, weight and feel. When in their best estate a striking geometric form attracts attention. This is a crystal. Minerals are usually hard, although a few are quite soft; most of them are two and one-half times heavier than water: Yet the common iron ore of Minnesota, hematite, is about five times, while a piece of rock salt or a crystal of sulphur is but little more than two times as heavy. The first glance will show whether a mineral will break with an easy, natural fracture along some plane or direction; if so, the mineral is said to possess cleavage; if not, it has only fracture, that is, it breaks in an ordinary way. The feel of a mineral sometimes aids the judgment in classifying: quartz feels hard and smooth; talc soft and greasy, and so on. The lustre of minerals is the property depending on the way they reflect light;

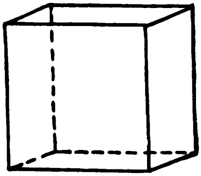

Fig. 146. A cube. The form in which the sulphide of lead, galenite, commonly occurs.

some are glassy, like quartz; others silky, like asbestus; and many are metallic, like gold and galenite. Color is a character too well known to dwell upon.

Some Modes of Occurrence. Minerals for the most part occur aggregated into clusters, or in those masses we name rocks. But it is when they occur alone or as somewhat scattered aggregates that they command our highest interest. It is then that they can grow into regular shapes with smooth faces, sharp edges and well-bounded angles. Such forms are called crystals. Each mineral species always grows into a crystal form peculiar to itself. Garnets assume one form, quartz another, and feldspar still another.

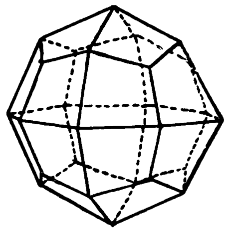

Fig. 147. A Trisoctahedron. The form in which garnets are frequently seen.

Most minerals are solid; yet a few occur in a viscid or fluid state, and still fewer are even gaseous as they are known to us ordinarily. Water, which is a very universal mineral, and mercury, are examples of minerals fluid at the ordinary temperature under which they exist. Apply such temperature as Minnesota climate can produce, and both become solidified into strikingly beautiful crystals or crystalline masses. Minerals which are gases at ordinary temperatures are less easy to discover.

On the other hand, every mineral known may exist in all three of the states in which matter occurs, namely, gaseous, fluid, and solid. That they are ordinarily found in only one of these three states is due to their

physical properties. In water, as an illustration directly at hand, we have a substance which, with only a few degrees of temperature variation, can be made to pass through all three states. A lump of ice in a test-tube over a flame will in a moment become fluid, and in another moment will rapidly disappear from sight as gaseous matter. Lead, a solid, is converted into a flowing mass at a temperature 3½ times as high as that necessary to boil water. It very soon goes over into a gas, to be seized upon instantly by the oxygen in the air, with which it forms a white clean-looking powder as soon as the temperature of the new compound is low enough. Gold, to add one more illustration, fuses at 1200° centigrade and becomes a thick vapor at a still higher temperature.

Symmetry among Minerals. After noting the characters color, hardness, weight, etc., as a mineral is inspected, one looks for some shape and symmetry about it. A few minerals possess no apparent shape or form habit; such are called amorphous which means without form. Many others have form. They are strikingly beautiful. Their faces are smooth and clear, angles sharp and well-defined, and edges bounding the faces very straight. All these characters are determined by an inward, a molecular symmetry which dominates the molding of the form. Yet there is a wonderful versatility in this symmetry. While the forms of crystals are classified under only six systems or thirty-two groups, there are many thousands of them in the mineral kingdom. Nearly eight hundred different forms of calcite alone have been found, and calcite is only one of the many hundreds of minerals already named although, it must be said, it is one of the most abundant of them.

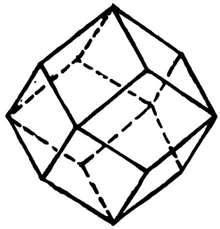

Fig. 148. A dodecahedron. Another crystal form under which Minnesota garnets occur.

Between the two extremes just noted, the formless and the perfect form, lies the great mass of the mineral kingdom. It is composed of those individuals in which the tendency to take on a crystal form exists, but the process of crystal building has been interrupted through the presence of so many individuals that neighborly contact prevents completion. This condition is the crystalline.

Where Minerals are Found. Minnesota schoolboys will find a never failing supply of minerals in the rocks. Go to the cliffs and quarries; search for minute caves and grottes; within them will be found many beautiful crystal forms. Upon the prairies and within the forests are countless boulders, boulderets and pebbles; within them also are frequent nests of quartz, calcite, garnet, pyrite, and other minerals. Along the streams in every part of the state stones are washed clean and ready for the explorer's hammer.

It is not to be expected that all the minerals named in the books can be found. If one-twenty-fifth part of the 1200 to 1500 now known can be added to the school cabinet, great success will have been attained. In the next chapter is a partial list of Minnesota minerals. Gather them all into the school collection.

CHAPTER XXXIII.

SOME COMMON MINNESOTA MINERALS.

Quartz—The feldspars— Hornblendes and augites—The micas—Calcite—Dolomite—The clays—Other minerals; garnet, staurolite, epidote, thomsonite — The sulphides; iron pyrites, chalcopyrite, bornite, galenite — The iron ores; magnetite, hematite, limonite—The resources of the glacial drift.

MANY HUNDREDS OF MINERALS are known in the world. Yet the number found in any one district is surprisingly small. It is unlikely that the most zealous collector will ever find one hundred species in Minnesota. In 1882 only seventy-three species could be named. To one interested in the study of the state the most common ones should be known. The following notes are given:

Quartz. First in the list of common minerals is quartz. The chemical compound, the oxide of silicon, called silica, of which quartz consists, comprises about one-half of all the solid substances of the earth's crust. The form it takes on is that of a prism and pyramid, or a pyramid alone, of six sides. Often when the crystals grow in clusters only two or three of the faces are formed and these but partially. In this crystallized state quartz is one of the most beautiful minerals we have. When clear the crystals are as transparent as water; when colored purple they are the amethyst,

when brown, a rare occurrence in this state, the cairngorm stone. Quartz in all its varieties is harder than the best pocket knife. It cannot be dissolved nor corroded by the strongest acids nor melted in any but the intensest heat. For these reasons quartz crystals and grains grown millions of years ago are in fresh condition now.

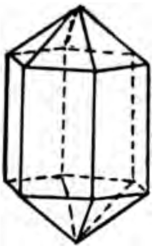

Fig. 149. Hexagonal prism and pyramids. The form sometimes attained by quartz.

The sandstones and quartzites found in many places are made up of rounded quartz grains; the sand along the streams, beside the lakes and in the glacial drift is of the same material; the jasper and jáspilite of the miners are finely crystalline quartz, colored beautifully red with oxide of iron; agate, another variety, sometimes called carnelian, is one of the most beautiful ornamental stones the state affords. It is variegated by different colored bands arranged in delicate, more or less wavy to zigzag lines. The bands, usually quite parallel, follow the outline of the cavity in which the form is grown. Chert is impure chalcedony without banded structure.

The Feldspars. The feldspars constitute a very important mineral group. There are certain physical differences among the several members of the group which are intimately associated with the internal form conditions known to exist. Bound up with these are certain chemical differences, neither of which can here be discussed. As a group they are white, varying to red, gray and green in many shades; they all cleave

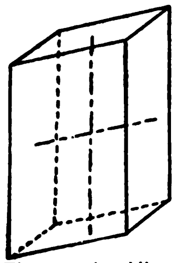

Fig. 150. An oblique prism. The essential form of the feldspars

readily in two directions and are too hard to scratch with the knife. They are as heavy as quartz. Feldspars are found in many rocks: gneisses along the Minnesota; granites in and around Saint Cloud, on the Giants range and along the northern boundary; gabbros at Duluth and diabases at Chengwatana and all along the north shore of lake Superior. By their decay feldspars form kaolin or clay. Rocks and boulders show every grade of decomposition.

Hornblendes and Augites. These are rock-making minerals. Very rarely indeed are individuals found elsewhere than in the gneisses, granites, schists and dark-colored volcanics. They occur in many colors, but are usually green and brown. They are heavier than the feldspars but not quite so hard.

The Micas. These minerals are characterized first of all by an eminent cleavage in one direction. The micas frequently found in the state are muscovite and biotite. Muscovite is silvery white and splits into extremely thin leaves. When the leaves are several inches across they can be used in stoves and crushed into a flaky powder for a lubricant. Biotite is glistening black, brown and green in color. When the disintegrating micas are stained golden yellow by iron oxide they are deceiving until understood.

Calcite. This is the most prominent member of the group called carbonates. Next to quartz it is the most common mineral in the state. It frequently occurs in beautiful crystals of two different geometrical shapes, the rhombohedron, and a scalenohedron which, from its peculiar shape, gives the name dog-tooth spar to its crystals. Calcite is so soft that it can be cut easily, it cleaves perfectly in three directions yielding rhombohedral fragments, two characters by which it can almost always be recognized.

Calcite also occurs granular; in this form it makes thick beds of limestone, as in the layers quarried at Saint Paul and Minneapolis. When deposited by waters, encrusting vegetation or coating rock surfaces, it is known as travertine.

Dolomite. This mineral is closely related to calcite. It forms, in its granular condition, the principal constituent of the building stone quarried at Winona, Red Wing, Kasota, Mankato and other places.

The Clays. Clay is a common earth. When dry, it is hard, compact, brittle; when wet, it is heavy, plastic and tenacious. Such are the characters of all good clays. Clay is derived from the degradation of feldspar. As it is transported, other products of decomposition are carried with it and an impure clay deposit results. The clays constitute an invaluable building material which, with the disappearance of the forests, will be much more widely used.

Other Minerals. Besides those that have been named, all of which enter so largely into the composition of Minnesota rocks, are others not necessary in rock-making but which are associated in the process. A few particularly common are: Garnet, quite generally found in the granites, gneisses and schists; staurolite, or cross stone, found in beautiful crystals below Little Falls; epidote, a green mineral, existing under a wide range of associations. Crystals of gypsum called selenite are frequent in certain localities in the state. Thomsonite, lintonite, prehnite, laumontite, and a number more occur in the ancient volcanics of the north-

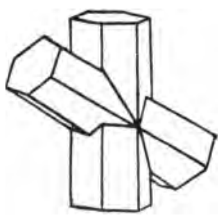

Fig. 151. The cross stone twin seen in many staurolite crystals.

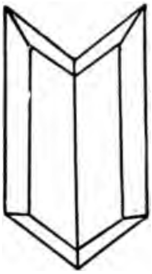

Fig. 152. A swallow-tail twin crystal. The form gypsum frequently assumes.

eastern corner of the state. They are secondary minerals, formed at the disintegration of earlier ones. With these minerals metallic copper is often found.

The Sulphides. Sulphides are compounds of sulphur and metals. In some states they have high value for the metals they bear, and on this account attract attention. Iron pyrites, or pyrite, is a very common mineral everywhere. It occurs in beautiful crystals, small crystalline lumps and concretionary masses

Fig. 153. A view of the Biwabik mine. The narrow light colored band at the top is glacial drift. Below this is hematite ore of iron of excellent quality, the bottom of which is not yet reached. Its gentle structure slope toward the south is clearly seen.

of many shapes. Chalcopyrite and bornite, both com-

pounds carrying copper, are found in northeastern Minnesota. The former has a strong brass yellow color and the latter a purple bronze. Galenite, the chief ore of lead in the neighboring states of Wisconsin, Illinois and Iowa, is frequent. Its blue black color, cubic form, perfect cubic cleavage, softness, fusibility and heaviness make it one of the readily distinguished sulphides.

The Iron Ores. Three of these minerals occur in Minnesota: Magnetite is the magnetic oxide, black, heavy and opaque. It occurs in masses and in scattered grains. Hematite, the red oxide, is by far the most prominent and valuable ore in the state. It occurs in two varieties; hard hematite as on the Vermilion range, where it is black and crystalline, and soft hematite, along the Mesabi, where it is soft and crumbling. Limonite, the brown or yellow oxide, is more or less associated with the hematite of the Mesabi range. Elsewhere it colors many rocks and is not infrequently segregated in swamps present and extinct. This ore contains water. The amount is as high as 280 pounds in every ton.

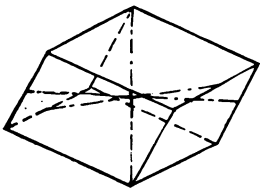

Fig. 154. The rhombohedron. This is one of the forms calcite, dolomite and hematite assume.

All the forgoing and many more can be found in almost every section of the state by breaking up the boulders in the glacial drift. It not infrequently happens that beautiful crystals are discovered in this way. Excursions to sandbanks and railway cuts are frequently fruitful in returns of this kind of geographic material.

CHAPTER XXXIV.

ROCKS.

Universe material; Meteorites—Characters of rocks—Distribution of rocks—Origin of rocks—Minnesota's ancient volcanoes—Eruptive rocks—Some later changes—Sedimentary rocks—Influence of living creatures upon rock-building.

THE SOLID PORTION of the earth we name rocks. They are found everywhere and exhibit wonderful variety in physical characters. Some are so hard that the best steel tools make slow progress in their cutting, others so soft that they are crumbled by the fingers, yet most of them possess a medium hardness and an average resistance to the forces and influences that make for degradation.

Universe Material. Rocks are also regarded as universe material. Meteorites that come to earth are made up for the most part of minerals very or quite like those found in the rock masses of the earth. One of the most common minerals in these bodies, and several meteorites have fallen upon Minnesota, is metallic iron; another is a peculiar compound of iron and sulphur, both of which elements occur in large quantities in the earth. To be sure it is not known whence

these visiting meteorites come, but many who have studied them think they are fragments that spring from the planetary regions of the solar system. As they come towards the earth, loosened from their moorings, they begin to whirl independently through space and at last, within the attractive sphere of influence of the earth, they are steadily brought to our globe. Should it prove true that meteorites come from other worlds in the solar system, they show the same chemical elements existing there as are within this planet, a circumstance which causes us to regard them with a neighborly interest as we turn to astronomy and seek to become aquainted with these "other worlds than ours."

Characters of Rocks. Color is one of the first characteristics we note. Some rocks are black; others white; still others gray, red, brown or other color, all in every imaginable shade. In chemical characters wide diversity is to be seen. One need go no farther than the first nest of boulders to see this illustrated. In almost any boulder bed may be found a dozen different rock species. One boulder is a granite, another a gneiss, and others diabase, porphyrite, gabbro, felsite, quartz-porphyry, porphyry; quartzite, sandstone, schist, shale, slate, limestone, dolomite, and so on, to the end of a long list.

Distribution of Rocks. Rocks exist everywhere and under the most diverse conditions. They are made and destroyed continuously. Some of them are many millions of years old; others were made in this very morning of geologic time. The latest formed rocks always lie upon the older. Those last formed are, as a rule, the least changed from their original condition. If we were to dig deep enough, the oldest rocks would be found everywhere as a universal crust covering the

entire earth. Others were formed continuously upon them. Not a day has elapsed since the beginning of geologic time when rocks have not been formed, at one time in one place and at another time in another place, and all the time in some place. So rocks are everywhere, and, as we discover them, we read the story of change and perpetual progress.

Origin of Rocks. There are two ways and only two in which rocks have always been and are now being created: one is by eruptive processes, chiefly volcanic; and the other by the accumulation of debris of degraded rocks and remains of animal forms, which is called sedimentation. Rocks are sometimes so altered that evidence of their origin is obscure. That they had an origin no one can doubt, but we will trust to time and the unflagging industry of workers in the field of geology to make clear the story of many a mass of rocks of whose vicissitudes we now have no knowledge.

Minnesota's Ancient Volcanoes. We already know what volcanoes are. The examples in Italy, Hawaii, and the Philippines show what enormous masses of lava are poured out to cool as basalt, how many fissures are filled with material which afterwards forms dikes, and how rockdust even overwhelms cities, so much of it is scattered abroad. All these features we have in Minnesota on a scale more magnificent than at any of the spots just named. The lava streams of Vesuvius cover a paltry few square miles; Hawaii is only 4,000 square miles in total area; but in this state over 5,400 square miles are overspread with rocks as dark in color and as genuinely volcanic as are those of Vesuvius or Kilauea, and thousands of square miles more carry granites and other rocks that tell the story of stupenduous action long geologic ages ago. Many times within the history

of the state have volcanoes shaken the earth. No less than four periods of volcanic activity can be counted in the rocks as one walks the streets of Duluth. Taylors Falls shows repeated lava flows. Six or seven can easily be counted as one walks from the river to the

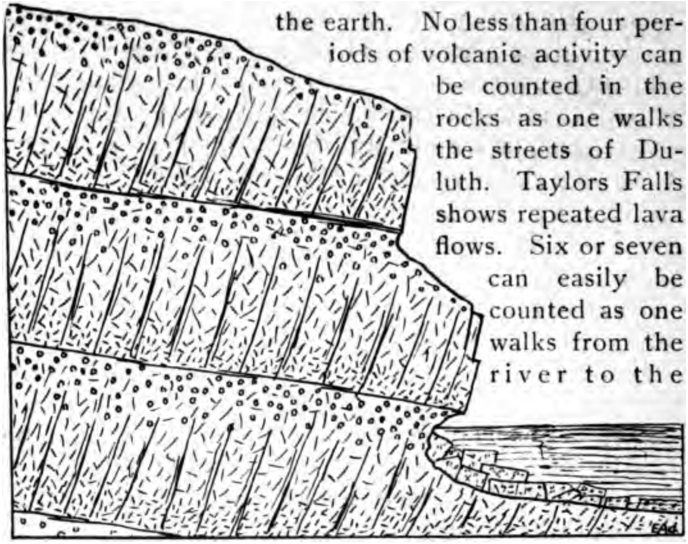

Fig. 155. Lava flows. A diagrammatic sketch to show their normal position one upon another and the porous upper part in whose pores, called amygdaloidal cavities, many minerals are deposited, the solidly crystalline middle part, and the finely compact bottom layer of each flow.

ledges around the schoolhouse. Chengwatana easily carries the palm, because 65 or more separate sheets of lava can be counted there. Saint Cloud is environed with rocks fused and thrust out by the tremendous earth forces that repeatedly centered their strength at this point and forged the rocks anew.

Eruptive Rocks. An eruptive rock is one that has been extruded from the earth. It may still lie in the vent or fissure of outflow, in which case it is a plug or dike. There are many dikes to be seen in this state. It may flow away from its opening; then it becomes a lava flow, and examples of such structures are to be

Fig. 156. A quartzite ledge. First formed as an ordinary sand, by the perfect cementing of the grains, this is now one of the hardest and most durable of rocks. Still it yields. The top of the Mound, near Luverne, looking east. *Photograph by C. J. Hibbard.*

seen in scores of places from Taylors Falls northward. Finally, the erupted rock may occur in great sheets thrust into the older rocks and pushed long distances into them by the tremendous force which displaced it from its original resting place. Such are the "sills" along the Ontarian boundary.

We are taught that the most important factor in a volcanic eruption is steam. Steam produces some important differences in the rocks. When it rushes out with such force that it blows the molten lava into shreds and particles, sometimes casting them high into the air to fall again as fragments, pumice, ash, and finally tuff are produced. When action is less violent, yet where much steam is present, lava flows out vigorously as a stream with its lower part compact and its upper a porous lava. The holes in this porous part as it came out of the

earth, are filled with steam, as the breath fills the bubbles in a bowl of soap suds. When the lava has lain millions of years, these holes become filled with various minerals and afford some most interesting spots in which to search for specimens. The filled cavities are called amygdules, that is, almond-shaped holes, and the rock carries the name amygdaloid. It is in these rocks, too, that the beautiful agates, chlorastrolites and thomsonites of lake Superior shores are found.

Some Later Changes. What has been said applies

Fig. 157. A boulder of contorted biotite gneiss. The minerals composing this rock have been arranged in alternate curving folia during the alteration the rock has undergone since its first solidification.

to erupted rocks in their condition as volcanic material.

But that is not the end. The ceaseless, yet slow, processes of nature are changing them. It is not alone at the surface that change proceeds, where the air, the rains, rivers, and the sun have free play; but hundreds and thousands of feet below the surface rocks and minerals yield particle by particle to pressure, warmth, moisture and the attraction of neighboring chemical atoms. As a result granites become gneisses, dark colored diabases become schists, ordinary dikes become that soaprock so eagerly followed by miners in some of the iron-bearing ranges around lake Superior for the ore which may lie upon it.

Sedimentary Rocks. These are made up of pieces or fragments of earlier rocks. The name fragmental is sometimes used to designate them; they are also called clastic. They are usually formed in water, and in the forming process the particles are shoved about until they are more or less rounded. The ocean border, lake basins, and river valleys of the globe are the places of most perceptible wear and continuous deposit. More rarely a volcanic ash or breccia is found, as at Taylors Falls. Some particles are coarse and make a conglomerate; others are medium, making sandstone; still others aggregate into a clay fine enough for the potter. Many strata of the earth have been formed in this way during the long periods of its history. The making of sedimentary rocks is doubtless proceeding now just as steadily and rapidly as at any time in earth history. If we go to any lake or river, the process can be seen in operation. Where the source of material is near at hand, the fragments are coarse, but where it is far away, they are fine. So boulder beds, gravels, sands, and muds of mingled clay and vegetable remains can be found. Any river shows

an instructive series of deposits along its shores and on the islands and sandbars in its channel. A little search will disclose great variation in the hardness of these sediments. In almost every locality, in time, the

Fig. 158. The upper part of the clay bed at the Clear Creek brick yard. This material, in which some layers contain much fine sand, was deposited on the bottom of the lake Nemadji of Chapter XXV.
Photograph by F. L. Barker.

grains become thoroughly cemented together and the rock so solid that it is a good and durable building stone. A series of hardened sands can be seen as we compare the accumulation of any lake shore; the

crumbling sandrock at Minneapolis, Saint Paul, Mankato or Winona; the quarry stone at Sandstone and Fond du Lac, and the thoroughly altered rock called quartzite at Luverne, Pipestone and Courtland.

Another series will be observed as one examines the clay to be found in hundreds of clay banks, the shale at Winona, Dresbach and Taylors Falls, the slaty rocks at Knife Falls and Carlton, and the slaty schists at Little Falls and Pike Rapids. The most remarkable, and economically the most interesting change of all is that of loose grains of an impure sand through a compact rock called taconite into iron ore. This has been accomplished along the Mesabi Iron range, and millions of tons of excellent ore are mined every year to the great advantage of the entire industrial world.

Influence of Living Creatures upon Rockbuilding. Again vast numbers of animals lived in the seas millions of years ago, just as is the case at present. As they died, generation after generation many thousand fold, the shells they made for protection against enemies and to serve for support that their soft bodies might be held in the best position for breathing, digesting food. and performing the other necessary functions of living, were dropped upon the sea bottom there to lie, slowly changing, until finally after almost a multitude of transitions they became the beds of dolomitic limestone and dolomite stretching across the state from the Minnesota to the Mississippi river. These rocks, the end of the series of limestones for this region, may be found in the quarries of Stillwater, Winona, Mankato, Kasota and Shakopee. One may hunt long in vain at these places for evidences of that earlier life that swarmed the seas once covering the ground where these flourishing towns now stand.

Minneapolis, Saint Paul, Faribault, Kenyon, Fountain and Spring Valley show less altered rocks. At these places, fossil forms in great variety and beauty can be gathered in enormous numbers. Indeed, these have for years afforded rich collecting grounds for those investigators who delight themselves and profit the

Fig. 159. A curve in the layer of dolomite, Northfield. This peculiar structure in a rock stratum generally horizontal may be due to certain chemical changes the rock has undergone.
Photograph by N. H. Winchell.

world by delving into the mysteries of ancient life and tracing the histories of families of creatures long since extinct, yet which in their day and generation were moulded by their environment of climate, food supply, and voracious enemies quite as much and in the same way as the populations of modern seas.

CHAPTER XXXV.

COMMON MINNESOTA ROCKS.

Differences in rocks—The Minnesota river valley—Central Minnesota—The International boundary—Vermilion and Mesabi—Northwest shore of lake Superior—Around Carlton and Cloquet—Eastern and southeastern Minnesota—Southwestern Minnesota—Rock variations.

WITHIN many portions of Minnesota the only visible rocks are the glacial drift and straggling river deposits. Thousands of square miles show not a rock beyond these incoherent masses. Locally, however, this material has been removed by weathering and erosion. It is along the sides of river valleys and more rarely beside lake shores that the older rocks are laid bare, those usually meant when rocks are mentioned.

Differences in Rocks. The first thing noted as the older rocks are compared is that they are not everywhere the same; the streams of northeastern Minnesota disclose one rock series and those of southeastern another and entirely different series while neither one is at all like the red quartzite series of the southwestern corner of the state.

The Minnesota River Valley. Were one to journey the Minnesota river valley from New Ulm to Ortonville a series of gneisses and schists would be traversed. These are doubtless among the very oldest rocks of the

earth's crust. Around La Framboise's, Morton, Beaver Falls, Vicksburgh, Granite Falls, Montevideo and Ortonville lie great exposures. Underground the rocks stretch westward beyond central South Dakota as determined by artesian well borings. They contain abundant quartz, glassy and hard and without cleav-

Fig. 160. A quarry of dark-colored, beautifully foliated granite-gniss, Beaver Falls. This is doubtless one of "the very oldest rocks of the earth's crust."
Photograph by Gertrude Brooks.

age; many feldspars with bright cleaved surfaces and white, pink or light brown color; green hornblende, and black shining scales of mica. At Redwood Falls, in places around Beaver Falls and Granite Falls the feldspar has slowly decayed until now there are occasional masses of impure kaolin and soft clay.

Central Minnesota. In the central part of the state very old rocks occur at Saint Cloud, Haven, Sauk Rapids, Watab, Rockville, Coldspring and Sauk Centre. They are granites in fresh condition and of excellent quarry quality. Around Little Falls schists and slates abound.

The International Boundary. Along the northern boundary of the state from Rainy lake to lake Superior are very ancient crystalline rocks. River banks and high bluffs expose ledge after ledge. Granite dikes of rare beauty and interest, folded and crushed schists, vertical masses and dark volcanics all appear. Intermingled with them, quite likely, are portions of the earth's original crust, that is, rocks as old as those of the Minnesota river valley.

Southward from the boundary in a succession of formations one upon another, rocks extend to the shores of lake Superior. Among them are the iron ore ranges.

The Vermilion and Mesabi Iron Ranges have already made the state world renowned as a producer of iron ore. Their discovery and the record of their development and exploitation form a striking chapter in the history of the commonwealth. Still other ore-producing ranges may be found before these are exhausted.

Northwest Shore of Lake Superior. Around Duluth and along the northwest shore of lake Superior is a series of ancient volcanics of most interesting types. They were injected into the earlier rocks as thick, heavy "sills," poured out as enormous lava flows, scattered as beds of volcanic ashes or injected as broad dikes within the older rocks. Another considerable district with its occasional exposures of ancient volcanic rocks, in the midst of which lie those of sedi-

mentary origin, is one comprising the lower Kettle river, the Snake river at Chengwatana and the Saint Croix river southward to Taylors Falls.

Around Carlton and Cloquet. Leaving the lake Superior district and passing southward, around Carlton and Cloquet are slates which have been quarried.

Fig. 161. A granite quarry, Saint Cloud. In this region are inexhaustible quantities of excellent granite.
Photograph by P. P. Colgrove.

Associated with them are dark colored schists. These continue until Sturgeon lake is passed. Between this point and Saint Cloud they have given way and the enormous granite masses of central Minnesota have taken their place. Thereby the economic conditions of the region are changed to a notable degree.

Eastern and Southeastern Minnesota. At Sand-

Fig. 162. Lava flows at Duluth. The upper falls of Lester creek. Erosion has profiled the rocks so that several flows are in sight one above the other.
Photograph by A. S. Williams.

stone and Hinckley a pink sandstone appears, prob-

ably a continuation of the brownstone of the Fond du Lac quarries. At Taylors Falls this becomes the white sandstone which, with some little color variation, continues to the Iowa state line. Interbedded with the sandstone are other rocks, also formed under water, but in the midst of somewhat different conditions.

Fig. 163. Roofing slate along the railroad track one and one-half miles below Cloquet. Originally clay sediment, afterward hardened, made crystalline and subjected to enormous horizontal pressure, a slaty cleavage exists which enables the quarryman to split large blocks into thin slabs.

They are shales and dolomites by name. Both are now quite different from what they first were. Throughout southeastern Minnesota are many places where these rocks occur. Between Mankato and Fort Snelling are some notable quarries; so, too, at Mantorville, Medford and other places between the two great

rivers. From Minneapolis and Stillwater to Jefferson scores more of favorable quarrying sites exist.

Southwestern Minnesota. Finally in southwestern Minnesota the red quartzites are almost the only rock. In Nicollet, Watonwan, Cottonwood, Pipestone and Rock counties these rocks are in sight. They are of great economic value and are classified among the hardest and most durable rocks. They are almost pure quartz whose grains are cemented together by the same material stained red with iron oxide. The catlinite, a layer of pipestone prized by the Indians, is a partially crystalline clay within the quartzite.

A slight experience in rock study will teach that the rocks here hurriedly enumerated vary as greatly in their power to resist disintegration as in their physical qualities. Some are hard and crystalline; others are loosely granular. As they differ in their quarry value so do they in their power to resist both internal and external forces which work their decomposition and removal. Their degradation as well as their formation has been an important factor in developing the geographical features which have thus far been our study.

CHAPTER XXXVI.

CONCLUDING CHAPTER.

A survey—The purpose of the book—Contour—The atmosphere—Weather and climate—Streams—Lakes and swamps—Forests and prairies—The illustrations—Home geography—Geography a science.

PHYSIOGRAPHICALLY MINNESOTA IS YOUNG. Her youth is shown in every physical feature. Those portions called old, when compared with general surface features within her borders or with neighboring regions, exhibit freshness and strength of outline. Because the state is young, because her form and every feature are of so recent fashioning, greater interest can be taken in tracing her growth and greater success will reward the student. The mind can come into close sympathy with the progress of things; the bond of contemporaneity is strong. Not alone greater interest and success; but greater ease of accomplishment. Lakes disappear, cataracts saw into the rocks, forests fade away and prairies become tree-covered before our very eyes, and all processes are seen to be in the very vigor of maturing strength. Within this environment field work, the study of the face of the commonwealth, will give such direction to the understanding and such varied experiences to the student-life that "the science of the earth in its relation to man," will bring into bold relief

the oneness of the soil and the man who tills it, and convince the student that not only human history but all organic history has its goal in man himself.

This book is devoted to elementary matters. No geographic feature of the state has been mentioned which should not be familiar to every boy and girl. Still it is of far more concern as the years go on that they know much more than these pages contain. That further study may be prosecuted the following suggestions form the closing chapter. They are commended alike to teacher and pupil, to all learners.

Contour. In every occupation geographical surroundings exert a controlling effect. The engineer who has for his problem the location of a railway recognizes this as later does the railway manager who has to deal with its earning capacity. So, too, does the manufacturer who seeks for power, for outlets marketward and easy access to his supply of raw material. Yet no man quicker than the farmer recognizes the effects of contour; the direction of successful drainage, easy haulage, and the conditions of comfort, health and social life are matters of prime concern.

It has been said physical environment groups the controls of man's ways of doing things. As a sort of converse, the things men do may be grouped as a response to the elements of their physical environment. Work out this proposition in one of its aspects as chapters I and II are reflected upon.

The Atmosphere. This outermost envelope of the earth becomes an agent of great efficiency. Not alone in composition and physical characters does it act, but as a mechanical force of extensive proportions it is powerful for destruction and re-construction. Weathered rock surfaces and transported debris are well-nigh

universal. The humidity, temperature and movements of the atmosphere become potent factors in directing the activities of mankind. The work of the Weather Bureau affords exceptional opportunity for becoming familiar with

Weather and Climate. The center of study here should be the weather map and local weather conditions determined by observation. Two points must be held in mind; the weather study of the state should be continued with unremitting observation of successive cyclonic areas, moisture conditions of the atmosphere, and temperature; and the grander continental conditions of which those of Minnesota form but a small part. Weather records continued almost uninterruptedly for seventy-five years in the upper Mississippi region show little change in temperature or rainfall.

Waters in the Ground. The varying condition of the rocks of the state brings about many differences in the run-off of the streams, determines the extent and distribution of springs and the quality as well as amount of well and spring water. Artesian wells are becoming increasingly important as a water supply: the conditions controlling them have been sedulously investigated during recent years and much has been added to our knowledge.

The sanitary and economic problems involved in the study of waters in the ground are of far-reaching importance. There is not a township in the state where knowledge in this field cannot be pursued with profit.

Streams. Much has already been said in several chapters touching flowing surface waters. The youth of the state and the sharp relief incident thereto afford excellent opportunities for investigation. He who also

observes the disposition of land waste closely will soon learn that he has before him a problem of no mean proportions. As age comes on in the life history of streams the load of land waste diminishes, and other physiographic conditions change slowly and steadily. The neighborhood rill or creek will afford varied illustrations. From the standpoint of human utility the rapids and waterfalls are in their prime.

Lakes and Swamps. Not in North America is there a more favorable place for the study of fresh water lakes and swamps than Minnesota presents. Beds where scores of lakes existed during glacial time, generally due to the northward slope of the land, give opportunity to study the development of lacustrine soils. The varied forms of existing lakes, with growing and waning swamps, nestling by thousands among morainic belts; rock basins of varied type, and manifold phases of alluvial plain formation with silted areas and oxbow lakes along the streams afford a most fascinating field for study.

Forests and Praires. Here the economic questions are varied and of growing interest. The contact between two grand vegetation areas stretches for hundreds of miles diagonally across the state. Again, the relations of trees to streams and lakes and the occasion for "openings" and small prairie patches within the forest are not yet fully understood.

The influence of the prairies upon the settlement and development of the middle west is a fruitful theme which Minnesota's physical and political history partially illumines. The dominant place of the pine in the early history of the state and its relation to her present wealth and progress are topics always fresh and stimulating.

The Illustrations. Much time was spent in illustrating this work. In the author's mind there is a story in every picture and the story bears a lesson. Emerson once remarked "I now require this of all pictures that they domesticate me, not that they dazzle me." Many geographic lessons are best and quickest taught through pictures, while the pictures themselves may be of the most varied types, from actual landscapes to sketches and profiles of very ideal conditions.

The eye is used more than all other senses together in the acquisition of knowledge. Economy of time demands the free use of illustrations. Environment is most forcibly presented by profiles, sketches and photographs. The pencil and the camera have come into almost universal use. The stream, valley, mine and artesian well give remarkable aid toward discovery beneath the surface.

Home Geography. The geography with which to occupy the earlier years in largest measure is, beyond question, home geography. This lies in field lessons from day to day in the school-yard, the township and the county; these lessons in some sequence are followed by a survey of the broader features of the commonwealth. This means the evolution of attention from matters of location into those of reasons why, applied to the many problems of location for the farm and the factory; the mine, mill and railway; to the questions of products involved in soils and climate, and in the more complex phases of municipal growth incident to the utilization of the material resources of the state and the disposal of surplus products.

Geography a Science. Geography thus studied becomes a new field for obtaining intellectual satisfac

tion. It gives redoubled relish to travel, furnishes crumbs of comfort to those who remain at home and becomes the formula for solving economic and social problems. The causes of geographic forms arouses inquiry; their cycle of development can be followed and the maturing conditions of each stage become better understood. Is it then appreciated that land forms have a history as well as the institutions which are founded upon them. Given this appreciation, and such a study of geography as shall make clear the causes of events and asssociate them with those geographic conditions that establish the relations of earth and man and the study becomes scientific; Geography is a Science.

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